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ARCHEAN ROCK PACKAGE IN THE RUBY RANGE,

SOUTHWESTERN MONTANA


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B.A., Western State College, Colorado, 1984

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

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Date _____

June 2, 1986

ABSTRACT

Schaefer, Michael J., M.S., Spring 1986

Geology

Petrology, Origin, and Tectonic Interpretation of an Archean Rock Package in the Ruby Range, Southwestern Montana (111 p.)

Director: David Alt

The Ruby Range of southwestern Montana contains Archean amphibolite- to granulite-facies metamorphic rocks belonging to three major units. The Cherry Creek Group is a meta-sedimentary unit dominated by concordantly interlayered units of marble, pelitic schist and gneisses, quartzite, calc-silicate gneisses, iron-formation, and amphibolites representing basaltic flows and sills. Structurally below this group is the Dillon gneiss, a quartzo-feldspathic gneiss of questionable origin. Possible protoliths include arkose, mudstone or siltstone rich in illite and quartz, mixed sediments and volcanics, and intrusive granite. The preferred origin is a synkinematic granitic intrusion with some interlayered sediments. Within this gneiss are several concordant layers of marble and amphibolite. Structurally below the Dillon gneiss is the pre-Cherry Creek Group. This group consists of biotite-quartz-plagioclase gneiss, biotite-garnet-quartz-plagioclase gneiss, sillimanite-garnet-quartz-plagioclase gneiss, hornblende-biotite gneiss, and hornblende gneiss. This unit is believed to be largely sedimentary in origin, with a greywacke protolith. Concordantly interlayered with these gneisses are basaltic amphibolites.

Small pods of tectonically emplaced meta-ultramafic rock were emplaced into all these units prior to or during high-grade metamorphism. These rocks are believed to have been emplaced as serpentized and partially serpentized peridotites.

A proposed tectonic model for the origin of this rock package consists of; 1) deposition of the pre-Cherry Creek unit as a basinal greywacke sequence, and possibly burial and metamorphism (3.1 b.y.) of this sequence to form an early basement, 2) deposition of the Cherry Creek Group in a stable shelf environment, possibly during a period of rifting, and 3) upper amphibolite grade metamorphism, deformation, migmatization of the pre-Cherry Creek Group, and concordant intrusion of the Dillon gneiss along the pre-Cherry Creek Group/Cherry Creek Group contact; all occurring 2.75 b.y. ago. A collision environment is preferred for this latest event.

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CHAPTER I

INTRODUCTION

Archean rocks of southwestern Montana are the northwestern most exposures of rock in the Archean Wyoming province. The Ruby Range of southwestern Montana contains highly deformed and metamorphosed rocks of various sedimentary and igneous origins. In the Ruby Range high grade metamorphism of upper amphibolite to granulite grade has been dated at 2.75 b.y. (James and Hedge, 1980). Three distinct metamorphic suites exist in the Ruby Range; the Cherry Creek Group, the Dillon gneiss, and the pre-Cherry Creek Group. Recent opinion to abandon such names for more descriptive terms, may help in correlations of units across mountain ranges in southwestern Montana. However, these terms will be retained here for simplicity and because of the strong belief that each unit represents a distinct rock package formed in a different environment. Figure 1 shows the distribution of these rock packages in the Ruby Range.

The Cherry Creek Group was first described and named by Peale (1896). This group is dominated by a stable shelf sequence of sedimentary rocks. The presence of marble is the distinguishing characteristic of this rock package. Similar rock packages exist in the Tobbaco Root, Highland, Greenhorn, and southern Madison Ranges (Vitaliano et al, 1979; Karasevich et al, 1981; Berg, 1976; Erslev, 1983). Although rock packages are similar, correlation of units across

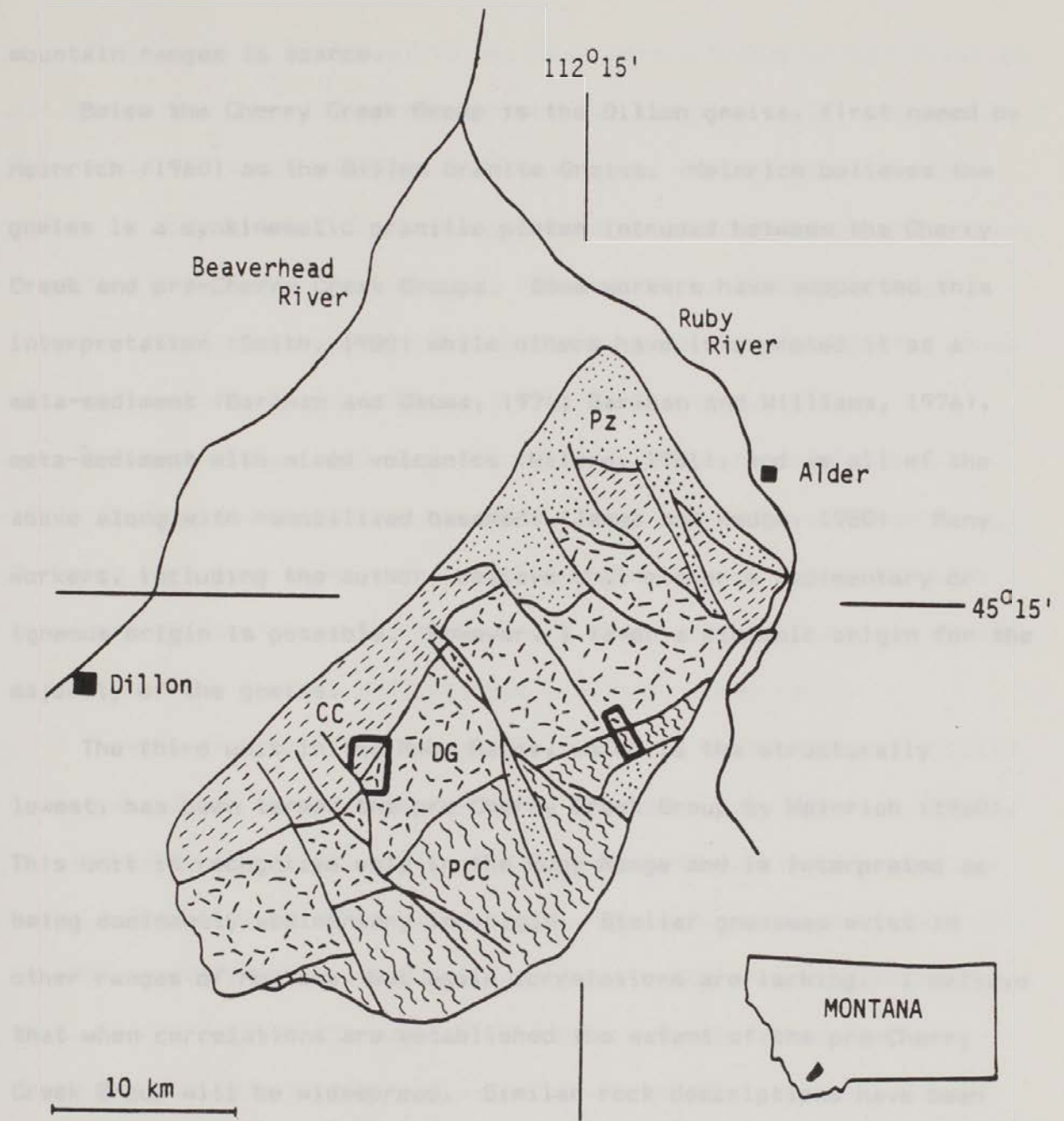


Figure 1. Schematic index map of the Ruby Range showing the distribution of the pre-Cherry Creek Group (PCC), Dillon gneiss (DG), Cherry Creek Group (CC), and Paleozoic sediments (Pz). Major faults trend northwest. The two heavy outlined areas are study area locations.

mountain ranges is scarce.

Below the Cherry Creek Group is the Dillon gneiss, first named by Heinrich (1960) as the Dillon Granite Gneiss. Heinrich believes the gneiss is a synkinematic granitic pluton intruded between the Cherry Creek and pre-Cherry Creek Groups. Some workers have supported this interpretation (Smith, 1980) while others have interpreted it as a meta-sediment (Garihan and Okuma, 1974; Garihan and Williams, 1976), meta-sediment with mixed volcanics (Wilson, 1981), and as all of the above along with remobilized basement (James and Hedge, 1980). Many workers, including the author, believe that either a sedimentary or igneous origin is possible. However, I favor a plutonic origin for the majority of the gneiss.

The third unit in the Ruby Range, which is the structurally lowest, has been termed the pre-Cherry Creek Group by Heinrich (1960). This unit is recognized only in the Ruby Range and is interpreted as being dominantly sedimentary in origin. Similar gneisses exist in other ranges of Montana, but again correlations are lacking. I believe that when correlations are established the extent of the pre-Cherry Creek Group will be widespread. Similar rock descriptions have been reported in the Tobbaco Root (Vitaliano et al 1979), Highland (Gordon, 1979), and Madison ranges (Erslev, 1983). Vitaliano et al (1979) suggested that the gneisses of the Tobbaco Root Mountains may correlate with those of the pre-Cherry Creek Group. This is based on the assumption that the sequences in the Tobbaco Root and Ruby Ranges are not overturned.

Small pods of tectonically emplaced meta-ultramafic rock exist in all the units. These pods are folded with the host rock, commonly in the crests of isoclinal folds. This suggests emplacement occurred before or during the 2.75 b.y. old metamorphic and deformational event. A regional thermal event, possibly related to the Hudsonian Orogeny (Condie, 1976), occurred 1.6 b.y. ago, and several episodes of diabase dike intrusion occurred 1.1 to 1.5 b.y. ago (Wooden, 1978).

Although these rocks have been mapped (Heinrich, 1960; Okuma, 1971; Garihan, 1973; Karasevich, 1980), some in detail, and descriptions for each rock type exist, very little has been done to tie the whole rock package together. Similarly, only a few attempts have been made to evaluate the history and tectonic origin of these rocks.

To evaluate the history and origin of this rock package I studied two areas within the Ruby Range during the summer of 1985, see figure 1. They were chosen for their good exposures of all the Archean rock types. The Sweetwater Pass study area, figure 2, contains rocks from the Cherry Creek Group and Dillon gneiss; the Cottonwood Creek study area, figure 3, contains rocks from the Dillon gneiss and pre-Cherry Creek Group. Several other areas were also briefly examined during this study. Maps prepared by Okuma (1971) and Garihan (1973) aided in mapping these rocks and allowed field work to focused on two major objectives; 1) sampling of each rock type for later petrologic analysis, and 2) observations of field relations and characteristics of each rock type. Field relations and analyses of approximately 80 thin sections were used in protolith determinations. Staining with sodium

tb Tertiary basalt

d Proterozoic diabase dike

ARCHEAN

dg Dillon gneiss

m Marble

am Amphibolite


p Pelitic schists and gneisses


csg Calc-silicate and related gneisses


qtz Meta-quartzite


if Iron-formation


cg Meta-conglomerate

 Strike and dip of bedding

 Strike and dip of foliation

 Synform showing plunge of axis

 Antiform showing trace of axial plane

 Overturned synform showing trace of axial plane


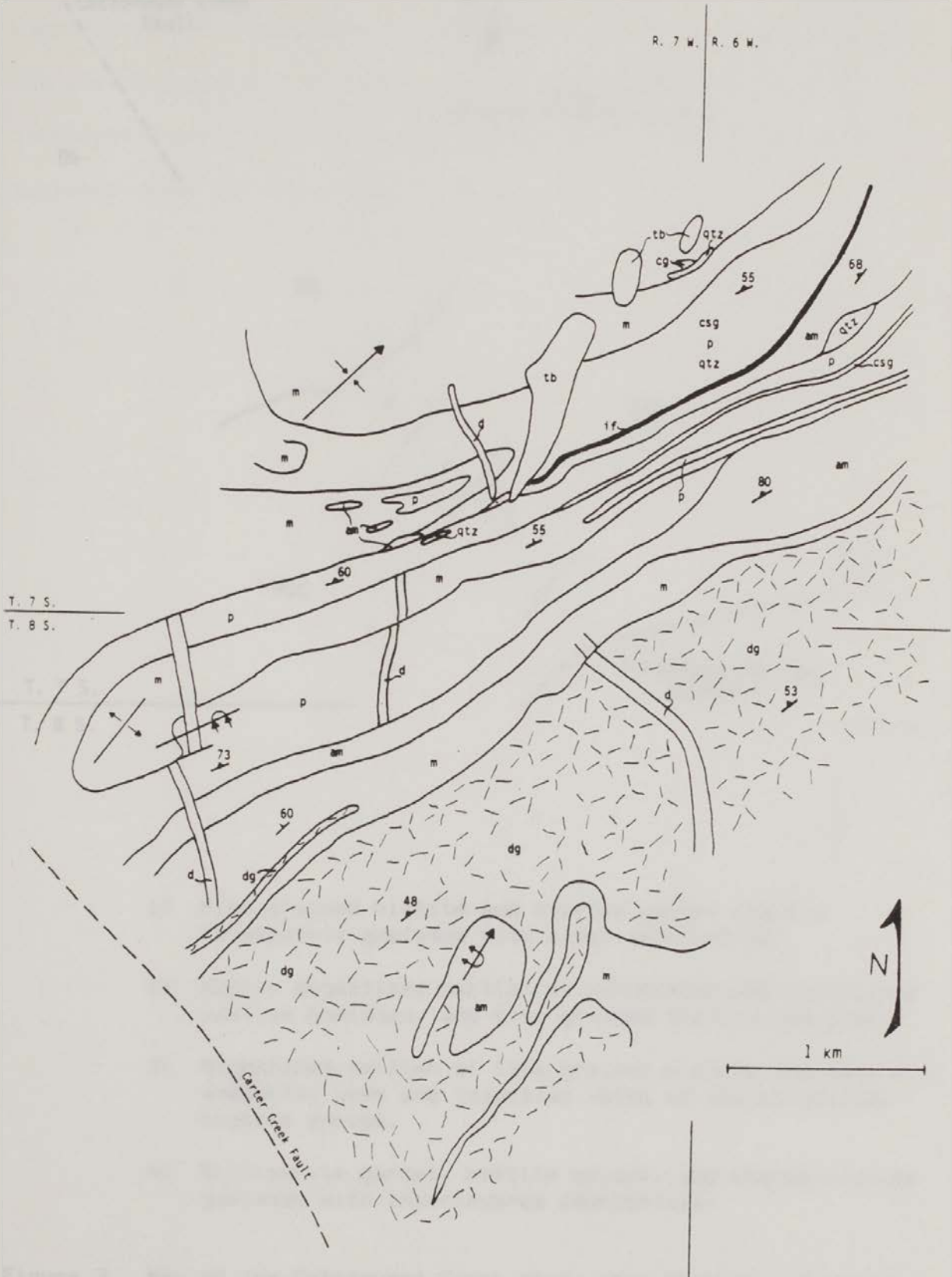
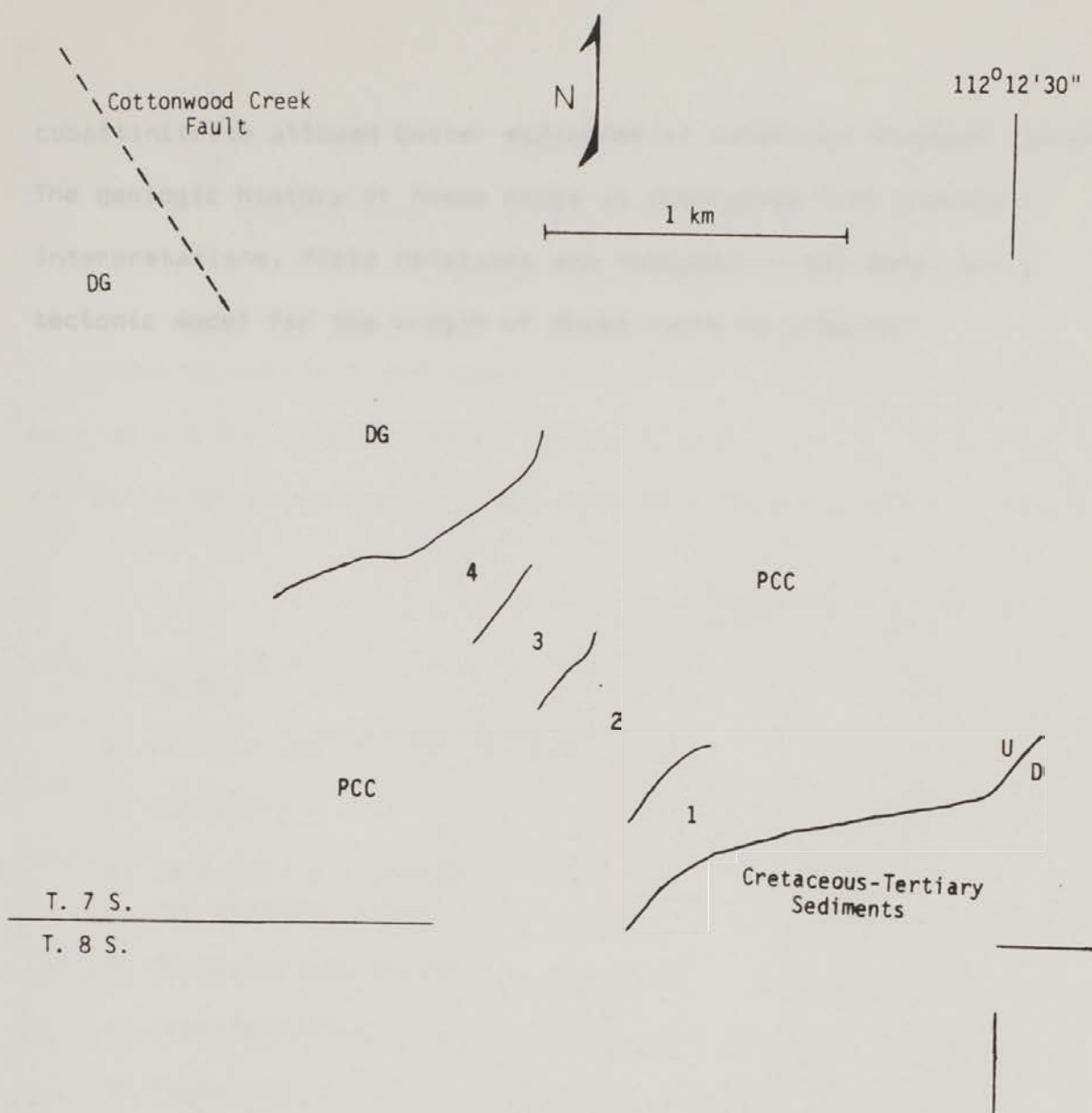
 Overturned antiform showing plunge of axis

Figure 2. Generalized geologic map of the Sweetwater Pass study area. All Archean units except the Dillon gneiss (dg) belong to the Cherry Creek Group.





- 1) Fine grained biotite and biotite garnet quartzofeldspathic gneisses with minor amphibolite
- 2) Highly migmatized section of hornblende and hornblende biotite gneisses, and fine grained biotite gneisses.
- 3) Migmatized section of fine grained biotite gneisses with anatectic pods and injection veins of coarse grained biotite gneiss.
- 4) Sillimanite garnet, biotite garnet, and coarse biotite gneisses with interlayered amphibolite.

Figure 3. Map of the Cottonwood Creek study area showing a traverse made through the Dillon gneiss (DG), and pre-Cherry Creek Group (PCC).

cobaltinitrite allowed better estimates of potassium feldspar contents. The geologic history of these rocks is determined from protolith interpretations, field relations and radiometric-age data, and a tectonic model for the origin of these rocks is proposed.

Several distinct rock types of dominantly sedimentary parentage make up the Cherry Creek Group. Listed is a list of the rock types and the estimated percentages of each from this study and Sarin (1973).

	Percentages	
	This study	Sarin, 1973
1) Marble	37	39
2) Pelitic schists and gneisses	23	19
3) Amphibolite	20	25
4) Calc-silicate gneiss and amphibolite	17	16
5) Actinolite gneiss	1	1
6) Iron formation	1	1
7) Pegmatite	1	1

Meta-ultramafic rocks are a minor component of the Cherry Creek Group, as well as the other two units. Two sets of pegmatite exist. One is generally concordant and probably related to intrusion of the Dillon gneiss. The second is crosscutting and probably related to post-deformation events.

All these rock types are concordantly interlayered and repeated throughout the exposures of the Cherry Creek Group. Thickness of

CHAPTER II

DESCRIPTIONS AND ORIGINS OF METAMORPHIC ROCKS

CHERRY CREEK GROUP

Several distinct rock types of dominantly sedimentary parentages make up the Cherry Creek Group. Below is a list of the rock types and the estimated percentages of each from this study and Garihan (1973).

	<u>Percentages</u>	
	This study	Garihan, 1973
1) Marble	37	39
2) Pelitic schists and gneisses	23	19
3) Amphibolite	20	24
4) Calc-silicate gneiss and meta-quartzite	17	16
5) Anthophyllite gneiss	1	1
6) Iron-formation	1	1
7) Pegmatite	1	--

Meta-ultramafic rocks are a minor component of the Cherry Creek Group, as well as the other two units. Two sets of pegmatite exist. One is generally concordant and probably related to intrusion of the Dillon gneiss. The second is crosscutting and probably related to post-Archean events.

All these rock types are concordantly interlayered and repeated throughout the exposures of the Cherry Creek Group. Thickness of

individual units varies greatly along strike and several of the more competent units such as meta-quartzite, amphibolite, and meta-ultramafic rocks, outcrop as boudins. The stratigraphy is unknown, so for the use of tectonic interpretations, the Cherry Creek Group is considered as a rock package rather than a stratigraphic section.

Marble

Marble generally forms continuous layers 155 to 425 m thick, and in one spot a small pod within amphibolite. Garihan (1973) reported continuous mappable layers as thin as 10 m. Plastic flow and isoclinal folding during metamorphism has obscured the true thickness of these layers. The rocks are layered on a centimeter to few meters scale. Layers differ in composition and probably represent original bedding. In one area, bedding on a 5 to 8 cm scale contains 10 to 15 cm layers of amphibolite. Other rock types within the marbles include: amphibolite pods, pegmatites generally as concordant pods with some crosscutting, a 15 to 30 m layer of Dillon gneiss, and a 20 to 30 m layer of pelitic schist.

Table 1 gives the modal abundances for a few of these marbles. Color ranges from white in pure marbles to pale green and pale brown in silicate-bearing varieties. Most commonly they are massive, medium- to coarse-grained mosaics of dominantly carbonate with 0.5 to 3 mm patches and layers of olivine, serpentine, and locally chlorite and diopside. Serpentine, mesh and fiber, is an alteration product from diopside (sample Rm-2) and olivine (Rm-1a), and iron oxide is a by-product of this alteration. Serpentine in sample Rm-3 is partly altered to

Table 1. Modal analyses of marble (Rm-) and calc-silicate (Rcs-) rocks of the Cherry Creek Group

Sample	Rm-0	Rm-2	Rm-3	Rm-4	RM-1a	Rcs-1	Rcs-3	Rcs-4
Carbonate	100	87	65	98	65	30	--	tr
Tremolite-actinolite	--	--	--	--	--	25	--	--
Hornblende	--	--	--	--	--	--	35	--
Diopside	--	1	--	1	--	--	--	65
Olivine	--	--	--	--	15	--	--	--
Scapolite	--	--	--	--	--	--	--	<1
Epidote	--	--	--	--	--	15	2	--
Biotite	--	--	--	--	--	--	7	27
Iron oxides	--	3	--	--	--	2	--	tr
Graphite	--	--	--	--	--	tr(?)	--	--
Garnet	--	--	--	--	--	2	--	--
Quartz	--	1	--	1	--	--	25	--
Potassium feldspar	--	--	--	--	--	15	25	2
Plagioclase	--	<1	--	--	--	tr	--	--
Zircon	--	--	--	--	--	tr	tr	tr
Apatite	--	--	--	--	--	--	tr	--
Sphene	--	--	--	--	--	<1	tr	tr
Tourmaline	--	--	--	--	--	--	--	tr
Serpentine	--	8	20	--	20	--	--	--
White mica/sericite	tr	--	--	<1	--	--	5	--
Chlorite	--	--	15	--	--	10	<1	1
Talc	--	--	--	--	--	--	--	5

chlorite. Traces of graphite, quartz, plagioclase, and muscovite are found sparsely scattered along carbonate grain boundaries. Pure marble is gradational to calc-silicate gneiss (see table 1). Garihan (1973) reports intermediate assemblages to those given here.

Heinrich (1947) and Levinson (1949) stained the marbles with Lemberg solution or copper nitrate and showed; 1) of the pure marbles, dolomitic marbles are twice as abundant as calcite ones, and 2) the marbles that contain calcium-magnesium or magnesium silicates, such as tremolite, actinolite, diopside, phlogopite, or olivine are dominantly calcitic. Heinrich (1960) interpreted the dominance of calcite in these rocks as due to the breakdown of dolomite.

Calc-Silicate and Related Gneiss

Gneisses under this heading grade from calc-silicate gneisses with abundant calcic minerals to predominantly silicic gneisses that contain appreciable amounts of hornblende/actinolite and biotite. The calc-silicate gneisses are in turn gradational to marbles. Table 1 gives the modal abundances of a few of the gneisses.

Calc-silicate gneisses with carbonate such as sample Rcs-1 are rather rare and tend to be closely associated with marble units. The calc-silicate gneiss of sample Rcs-1 is approximately 15 m thick, and fairly continuous along a marble-pelitic schist contact. This calc-silicate gneiss is banded greenish-gray to white, the silicic layers being the former, the calcic the later. The silicic layers consist of potassium feldspar and chlorite (altered from biotite). They are finer grained (0.1 to 0.4 mm) than the 0.5 to 1 mm grains of calcite, epidote

and tremolite in the calcic layers.

Other Cherry Creek gneisses have a dominant calcium-rich silicate mineral such as hornblende/actinolite (Rcs-3), or diopside (Rcs-4). These gneisses exist dominantly in one 300 m unit. Outcrops are generally poor and rock compositions variable. It is mapped on figure 2 as an undifferentiated unit of calc-silicate gneiss, meta-quartzite, and pelitic schist and gneiss. Samples Rcs-3, Rcs-4 (table 1) and Rsq-1 (table 2) were collected from this unit. Pelitic schist outcrops were infrequently encountered but abundant mica in the soil suggests that they underlie a good portion of the unexposed areas.

These gneisses were probably deposited as impure dolomites (Rcs-1), calcareous sands, and/or calcareous muds (Rcs-3, Rcs-4).

Meta-quartzite and Meta-conglomerate

Other workers in the Ruby Range (Garihan 1973, Wilson 1981a) have described three types of meta-quartzite; pure meta-quartzite, impure meta-quartzite, and calc-silicate meta-quartzite. Meta-quartzite was mappable in two places along strike, between amphibolite and pelitic layers. Meta-quartzite is also common as small boudins within marble. Slight variations in mica content and compositionally different layers, such as calc-silicate rich bands appear to represent bedding. Pale green almost pure meta-quartzite which gets its color from chrome mica (fuchsite) has been reported by Heinrich (1960) and Wilson (1981).

Three meta-quartzite modal abundances are in table 2. Compositional variations exist within meta-quartzite outcrops. Rq-2,

Table 2. Modal analyses of meta-quartzites and meta-conglomerate of the Cherry Creek Group

Sample	RsQ-1	Rq-1	Rq-2	Conglomerate Rcg-2	
				Matrix	Pebbles
Plagioclase	29	--	--	--	--
Potassium feldspar	20	--	--	45	--
Quartz	50	80	98	36	61
Biotite	1	--	2	12	--
Sillimanite	<1	--	--	--	35
Tremolite	--	7	--	--	--
Diopside	--	12	--	--	--
Tourmaline	--	--	--	tr	--
Iron oxide	--	--	--	5	4
Zircon	tr	--	--	tr	--
Apatite	--	tr	--	--	--
Carbonate	--	1	--	--	--
Muscovite	tr	--	--	1	--
Sericite	1	--	--	1	--
Talc	--	<1	--	--	--

an almost pure meta-quartzite, outcrops as a 1 m thick bed on the edge of a large (50 by 150 m) boudin shaped outcrop of Rsq-1 which is an impure meta-quartzite with a composition suggesting an arkosic protolith (table 2). Rsq-1 contains predominant quartz, plagioclase (An_{27}) and potassium feldspar. Potassium feldspar is microcline, orthoclase, and perthite. Microcline is 0.2 to 1.2 mm and interstitial, orthoclase forms larger crystals up to 3 mm, and perthite is generally orthoclase with aligned and twinned plagioclase inclusions. Sillimanite exists along thin veins cutting the rock.

Wilson (1981) interpreted the pure meta-quartzites as metamorphosed chert, rather than pure quartz sand, and argued in favor of an inorganic origin for the chert based on texture and its association with volcanogenic amphibolite and iron-formation. This same association is present in the study area, however, gradations from impure quartzites to pure quartzites within the same outcrop, suggest that some of the pure meta-quartzites, not associated with amphibolite and iron-formation, were quartz sands.

Sample Rq-1, a calc-silicate meta-quartzite, is mostly anhedral 1 to 4 mm quartz grains. Within this quartzite are thin layers composed of diopside, tremolite, calcite, and trace amounts of talc altering from diopside. Tremolite is commonly found within and around diopside crystals. Tremolite grading into larger diopside crystals and the presence of calcite closely associated with the tremolite, suggests that tremolite and calcite are unstable with respect to diopside. Thus, the reaction:

Tremolite + 3Calcite + 2Quartz --> 5Diopside + 3Carbon dioxide + Water
 which occurs at temperatures of 500 to 600°C and pressures of 1 to 4 kbar, is suggested.

One conglomerate bed was found in the hinge of a small fold. It is 10 to 15 m wide and continues only a short distance. Exposures of calcic silicate gneiss, sample Rcs-3, and a 1 m bed of quartzite exist nearby. Table 2 gives the mineral composition and abundances for this conglomerate. The pebbles, which make up 25% of the rock, are quartz with sillimanite. They are flattened and stretched, roughly 5 cm wide, 10 cm long and 3 cm thick. The matrix is medium-grained microcline, quartz, and biotite in a granoblastic texture.

Composition and field relations of these meta-quartzites and meta-conglomerates suggest they were deposited as quartz sands, arkosic sands, calcareous sands, and arkosic conglomerates.

Pelitic Schist and Gneiss

Pelitic rocks are common in the Cherry Creek Group. Most outcrops are rounded with low relief, weathered pale brown, and speckled with abundant mica flakes. Pelitic rocks generally form continuous units that range from 50 to 400 m in thickness, and commonly contain concordantly interlayered amphibolites (figure 4). Amphibolite interbeds vary from 5 cm to 2 m in thickness and make up as much as 15% of the pelitic units in some areas. Cleavage is well developed and foliation is strong. Banding of quartz-plagioclase-garnet with biotite layers is present in some outcrops and may be the result of lit-par-lit

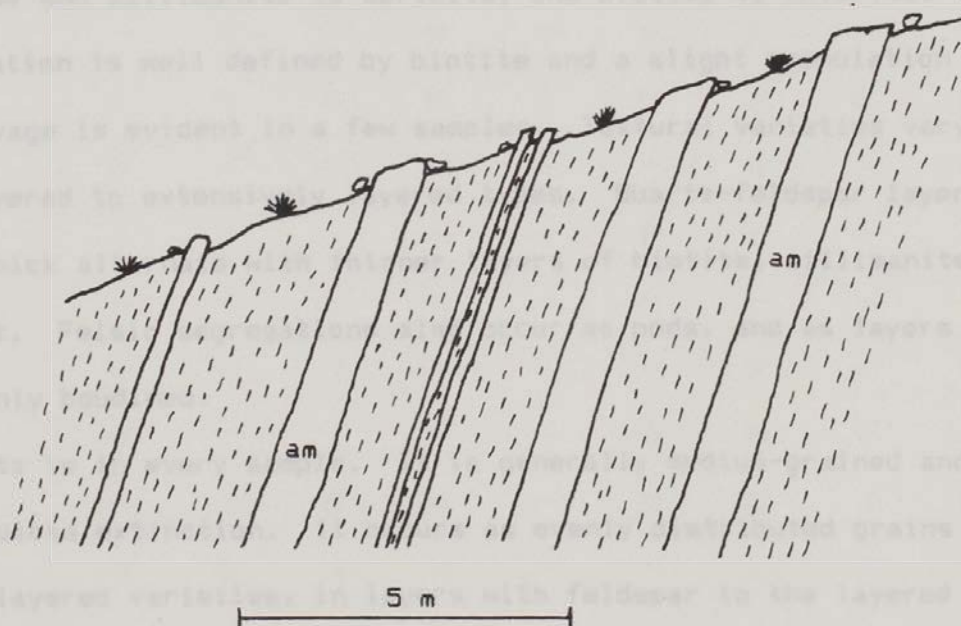


Figure 4. Picture showing amphibolite layer in pelitic schists, and a schematic sketch showing the trench in which this amphibolite layer is exposed. Thickness of individual layers of amphibolite (am) varies from 5 cm to 2 m.

injection as suggested by Heinrich (1960), Okuma (1971) and Garihan (1973). They may also represent original sedimentary layering, metamorphic differentiation, or partial melting.

Table 3 gives the estimated modal abundances for several pelitic rocks. Mineral percentages vary. Common assemblages include, in order of abundance:

- 1) Quartz + biotite + plagioclase \pm sillimanite \pm garnet
- 2) Quartz + potassium feldspar + plagioclase + biotite \pm sillimanite \pm garnet

In two areas within a pelitic unit, garnets up to 8 cm in diameter were found in the soil weathered from pelitic schists and amphibolitic interbeds. Retrograde metamorphism mostly involves alteration of plagioclase and sillimanite to sericite, and biotite to chlorite.

Foliation is well defined by biotite and a slight crenulation of this cleavage is evident in a few samples. Textural varieties vary from unlayered to extensively layered types. Quartz-feldspar layers up to 8 mm thick alternate with thinner layers of biotite, sillimanite, and garnet. Felsic segregations also occur as pods, and as layers that are commonly boudined.

Quartz is in every sample. It is generally medium-grained and shows undulose extinction. It occurs as evenly distributed grains in the less layered varieties, in layers with feldspar in the layered varieties, and in small fine-grained "buttons" with sillimanite (samples Rp-1 and Rp-8). Plagioclase, An_{26} to An_{32} , occurs as twinned and untwinned anhedral 0.5 to 3mm grains. Undulose extinction and

Table 3. Modal analyses of pelitic schists and gneisses of the Cherry Creek Group

Sample # (Rp-)	1	2	3	4	5*	6	7	8	9
Plagioclase	1	10	--	15	20	18	5	2	44
Potassium Feldspar	40	--	--	10	--	--	3	50	--
Quartz	19	41	21	50	15	30	28	11	30
Biotite	25	40	30	23	60	tr	25	25	20
Sillimanite	?	--	4	--	--	--	2	10	--
Garnet	1	5	3	2	--	5	3	--	5
Tourmaline	3	--	tr	--	--	--	tr	tr	--
Iron Oxide	3	2	6	<1	--	2	1	1	1
Rutile	--	--	--	tr	--	tr	tr	--	--
Zircon	tr	tr	tr	tr	--	tr	tr	tr	tr
Apatite	tr	--	--	--	--	--	tr	--	--
Graphite(?)	1	1	--	--	--	tr	--	--	--
Epidote	--	--	--	tr	--	--	--	--	--
Muscovite	--	--	2	--	--	--	tr	--	tr
Chlorite	tr	--	5	--	--	25	10	--	<1
Sericite	--	2	28	tr	--	20	23	1	tr
Hematite	tr	tr	1	--	--	--	tr	--	--

* Hand sample estimation

deformation twinning appear in sample Rp-9, antiperthite in Rp-1.

Potassium feldspar is gridiron twinned microcline in samples Rp-1 and Rp-8, and orthoclase in Rp-4 and Rp-7. Microcline, where present, makes up 40 to 50% of the rock. In samples with orthoclase only 3 to 10% is potassium feldspar. In sample Rp-8, microcline forms 2 to 6 mm grains containing inclusions of quartz, plagioclase and aligned biotite.

Biotite is the dominant mafic mineral. It is pleochroic from yellow to red-brown, 0.4 to 2 mm long, and defines a foliation. It commonly serves to nucleate sillimanite which forms fibrolite or diamond shaped cross sections and elongate blades. Sillimanite is commonly altered to sericite. In samples Rp-1 and Rp-8 sillimanite forms small "buttons" with quartz.

Garnet, presumably almandine, is pale pink to brown, forms 0.5 to 15 mm flattened porphyroblasts, and is commonly fractured with retrograde sericite and chlorite filling the fractures.

The mineral and modally estimated chemical compositions (Wilson 1981a) of these pelitic schists and gneisses are consistent with an aluminous shaley protolith.

Actinolite and Anthophyllite Schists

Pelitic schist units locally contain actinolite and anthophyllite schists. Table 4 contains estimated modal abundances for a few of these rocks. The rocks are generally medium grained and foliation is well defined by elongate amphibole crystals.

Table 4. Modal analyses of actinolite and anthophyllite schists of the Cherry Creek Group

Sample	Ran-1	Ran-2	Ran-3	Ran-4	Rp-4a
Plagioclase	2	2	30	--	15
Quartz	50	60	14	--	3
Biotite	--	tr	tr	--	tr
Garnet	<1	7	5	--	--
Actinolite	20	--	--	--	22
Anthophyllite	22	30	50	99	3
Iron Oxide	<1	--	--	1	2
Rutile	1	1	1	--	--
Zircon	--	tr	tr	tr	--
Apatite	tr	tr	tr	--	tr
Epidote	--	--	--	--	tr
Muscovite	--	--	--	--	tr
Chlorite	--	--	--	tr	30
Sericite	5	--	--	--	25
Serpentine	--	--	tr	<1	--

Anthophyllite/cummingtonite schist is an unusual rock type with a very high magnesium content unlike common sedimentary rocks; thus, in some cases it is believed to be metasomatized sediment (Williams et al 1982). The schists here are associated in many cases with meta-ultramafic rocks. Samples Ran-1, Ran-2 and Ran-3 were collected 5, 4, and 2 m respectively from a meta-ultramafic pod (Ru-1) within a thick pelitic sequence, and Ran-4 at the contact. The percentage of amphibole decreases away from the meta-ultramafic body whereas that of minerals characteristic of the pelitic rocks increases. These schists probably are metasomatized pelitic schists to which the meta-ultramafic body has supplied magnesium. Desmarais (1978) and Erslev (1980) noted reaction zones of actinolite (retrograde?), anthophyllite, and cummingtonite around meta-ultramafic rocks in the Ruby Range and Madison Range, respectively. Other anthophyllite/actinolite schists such as Rp-4a, not associated with meta-ultramafic rocks, exist as thin poorly defined layers within pelitic units, and may have impure dolomite protoliths.

Iron-Formation

Iron-formation exists as a continuous layer about 20 m thick associated with amphibolite, which is common for iron-formation throughout the range (Wilson 1981a). This iron-formation is massive to banded with the banded types consisting of 2 to 3 mm quartz layers (meta-chert) alternating with pyroxene and magnetite layers 2 to 5 mm thick. Table 5 gives the estimated modal abundances for a sample from this study and the range of abundances found by Wilson (1981a).

Table 5. Modal abundances of iron-formation from the Cherry Creek Group. Wilson (1981a) = the range for seven samples.

Sample	Rif-1	Wilson (1981a)
Quartz	50	30-55
Diopside-Salite	--	tr-30
Augite	5	10-30
Hypersthene	27	tr-35
Hornblende	tr	1-5
Anthophyllite	1	tr-1
Grunerite	2	1-5
Garnet	--	0-55
Magnetite	25	10-30
Apatite	tr	tr
Chlorite	--	0-1
Hematite	tr	tr-1

Archean iron-formation is generally regarded as chemically precipitated sediment. Models for precipitation are numerous and include upwelling, hydrothermal, evaporate, and weathering origins (Simonson, 1985). Gross (1980) gives the characteristics of the two major types of iron-formation, Superior and Algoma. Algoma-type iron-formation is associated with greywacke, turbidites, and abundant volcanic rocks; the Superior type with shale, quartzite, dolomite, and a lesser amount of volcanic rock. These types grade into each other and represent gradations into different tectonic environments; Superior includes shelf to slope and grades into the deeper water, volcanic arc, oceanic ridge, or rift related environments of the Algoma-type.

Wilson (1981a) believes that the Ruby Range iron-formation best fits into the volcanogenic Algoma type because of its close association with amphibolites and his belief that the Dillon gneiss has a greywacke protolith. Field relations in this study also show a close association of iron-formation and basaltic amphibolite. However, if one considers a slightly broader than outcrop association, it is clear that amphibolites are subordinate in the association compared to dolomitic marble, quartzite, and shale. This broader association is common for iron-formation throughout the basement of southwestern Montana (Bayley and James, 1973). Thus, I believe the iron formation in the Cherry Creek Group best fits the Superior type. The oxide and silicate minerals in these iron-formations (see table 5) are also consistent with the Superior type.

One problem with this interpretation is that Superior type iron-

formation is common only in Proterozoic sequences (Gross, 1980; Eriksson, 1983). This is probably the result of varying tectonic conditions rather than unique factors, such as atmospheric and biological changes, influencing the sedimentation of iron-formation (Gross, 1980). Windley (1984, pg.13) considered this problem, and suggested that iron-formation associations like that of the Cherry Creek Group represent a proto-Superior type that formed at a time when stable cratons were short lived. These iron-formations are distinct from the Algoma type common in greenstone belts. Windley emphasizes the important difference between; 1) greenstone belt sedimentary sequences of clastics, greywacke, flysch, conglomerate, shale, and Algoma iron-formation, that accumulate as unstable turbidite type deep sea deposits and 2) Archean high-grade supracrustal sequences like the Cherry Creek Group that accumulate in shallow water shelf to slope stable tectonic environments. These iron-formations probably accumulated on a semi-stable continental slope during a period of submarine volcanism in which associated amphibolites and possibly cherts were forming.

Amphibolite

Basaltic amphibolites make up one of the major rock types of the Cherry Creek Group. They are everywhere concordant, forming thin (5 cm to 2 m) interlayers with pelitic schists, thick layers (up to 250 meters) traceable for several kilometers along strike but variable in thickness, and small discontinuous lenses. Figure 2 shows only the

more prominent units. The pelitic schist units commonly have thin amphibolite interlayers (up to 15%). Figure 4 (p. 16) shows interlayering of amphibolite and pelitic schist with the amphibolite layers ranging from 5 cm to 2 m.

Amphibolite outcrops are blocky and ribbed reflecting the good subvertical development of cleavage. On weathered surfaces they are dark brown to black. Outcrops are generally homogenous. However, on some weathered surfaces slight centimeter scale layering of lighter and darker layers can be seen.

Hand samples present a "salt and pepper" appearance with roughly equal proportions of slightly foliated hornblende and plagioclase making up most of the rock. Conspicuous porphyroblasts of garnet average 1 to 4 mm and range from 0 to 20% with 0 to 5% being most common. In one area, amphibolite was found with 20% garnet porphyroblasts up to 2 cm in diameter. The reason for the variation in garnet content is probably related to original compositional variations. Veins are common, but volumetrically minor. Most are no more than 2 mm wide, and typically consist of quartz and plagioclase.

Thin sections reveal that the amphibolites have a granoblastic texture with well developed triple junctions. Slight foliation is defined by hornblende. Light and dark minerals are evenly distributed. The amphibolites are fairly consistent in mineral composition, table 6. Figure 5 is an ACKFm plot of these rocks. This plot shows amphibolite-facies assemblages for these rocks and emphasizes their constant composition. Hornblende and plagioclase are dominant with hornblende

Table 6. Modal analyses of Cherry Creek Group amphibolites

Sample # (RA-)	6	17	19	22	26	31	32	33	34	35	36	37
Hornblende	41	48	52	51	45	45	55	52	50	50	45	45
Plagioclase	44	35	43	40	50	45	33	26	25	15	40	45
Diopside	--	5	tr	2	--	--	--	1	--	2	--	--
Garnet	--	3	tr	--	--	1	tr	--	--	--	4	3
Quartz	3	7	2	3	2	3	2	3	2	2	4	3
Potassium feldspar	--	--	2	1	--	--	tr	2	<1	--	3	2
Sphene	--	1	--	1	<1	1	<1	1	--	--	--	--
Iron oxide	--	1	1	1	2	<1	2	1	1	2	3	2
Apatite	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Zircon	tr	tr	--	--	tr	--	tr	--	--	--	tr	tr
Muscovite	--	--	--	--	--	--	--	--	1	--	--	--
Biotite	1	--	tr	--	--	--	--	--	--	--	--	--
Cummingtonite	5	--	--	--	--	--	--	--	--	--	tr	--
Actinolite	--	--	--	--	--	--	--	1	1	tr	--	--
Sericite	1	tr	tr	tr	--	5	7	10	19	27	1	tr
Epidote	--	tr	tr	1	tr	tr	tr	2	<1	--	--	--
Chlorite	--	--	--	--	--	tr	tr	--	1	--	tr	--
Calcite	--	--	--	tr	--	--	tr	1	tr	1	<1	--
Hematite	--	--	--	--	--	--	tr	--	tr	tr	tr	tr

being slightly more abundant than plagioclase. Quartz and iron oxides are generally present in minor amounts and diopside, potassium feldspar, and garnet are common, but minor in amount. Biotite occurs in a few samples, muscovite in one. Alteration minerals include epidote, sericite, chlorite, calcite, actinolite and cummingtonite. They occur in thin 0.1 to 0.2 mm veins with quartz and plagioclase, as alterations near these veins, and as alterations of the major minerals.

Hornblende is pleochroic from yellow to green to greenish brown. The grains are elongate from 0.2 to 1.5 mm long and define a slight foliation. Cleavage is well developed and fractures are common. Inclusions of quartz, iron oxides, plagioclase and sphene are common.

Plagioclase is $An_{31}-An_{56}$ with the majority being andesine, $An_{31}-An_{36}$. Untwinned plagioclase is common but albite, pericline and local carlsbad twins also exist. Slight reverse zoning and undulose extinction were observed in a few samples. Grains are generally equant, averaging 0.2 to 0.6 mm. Alteration to sericite is extensive in some samples, minor in others.

Garnet, presumably almandine, is clear to pale pink. It occurs as poikiloblastic porphyroblasts averaging 1.5 to 5 mm with inclusions of hornblende, quartz, iron oxide, calcite, and epidote. Clinopyroxene of the diopside-salite series is pale green and occurs as anhedral fractured and cleaved grains averaging 0.2 to 0.4 mm. Quartz and potassium feldspar, where present, occur as 0.2 to 0.4 mm grains with well developed undulose extinction.

Possible protoliths for amphibolites include: 1) basaltic or

gabbro sills and dikes, 2) basaltic flows, 3) basaltic tuff or tuff mixed with carbonate, 4) shaley limestone or calcareous shale, and 5) metasomatically replaced marble or pyroxene granulite. Protolith 5 is excluded because; 1) evidence such as relict carbonate to support metasomatic replacement is lacking, and 2) pods of meta-ultramafic rock are common in the amphibolite layers; pods of meta-ultramafic rock are common with basalt protoliths but are not commonly associated with metasomatic amphibolites (A.E.J. Engel, personal communication, 1986).

A sedimentary origin, protolith 4, can be excluded because: 1) shaley limestone or calcareous shale protolith amphibolites tend to be compositionally layered as well as variable along strike, whereas those of the Cherry Creek Group are for the most part unlayered, and homogeneous (see table 6, and figure 5), and 2) sedimentary amphibolites are generally richer in hornblende than plagioclase, almandine is generally absent, and they may contain abundant biotite, quartz, diopside, or epidote (Hyndman 1985, p. 481-482). None of these are characteristic of the Cherry Creek Group amphibolites. These amphibolites are occasionally found interlayered with rocks of clearly sedimentary origin (pelitic schists), which is characteristic of sedimentary amphibolite protoliths. However, the above characteristics and the lack of gradation between the amphibolite and sedimentary interlayers lead me to believe a basaltic origin is the more probable.

Evidence supporting a basaltic protolith for these amphibolites includes: 1) The minerals present and their abundances are characteristic of basaltic protoliths. Hornblende and plagioclase are

roughly equal in abundance and garnet is a common accessory. 2) The mineralogy is quite homogeneous, see figure 5 and table 6. 3) The chemical composition, determined by Bielak (1978) and Wilson (1981) shows a close affinity to tholeiitic basalts. An AFM plot, figure 6, of these chemical analysis shows a tholeiitic trend. Similar amphibolites from the Tobacco Root Mountains have been analyzed by Burger (1969). Plots of Niggli magnesium against potassium, nickel against chromium, and magnesium against chromium and nickel, suggest these amphibolites originated from extrusive and/or concordant intrusive igneous rocks. Field relations show that these amphibolites originated in a sequence with interlayered argillaceous sediments (Burger, 1969, p.1332) similar to many of those found here.

The thicker layers, up to 250 m, may be explained by a flow or sill origin, however, the thickness of the thin 5 to 30 cm layers interlayered with pelitic rocks is at odds with a flow origin. Thinning due to deformation is unlikely because of their continuity of thickness (figure 4). If deformation were responsible one would expect boudinage, and pinch and swell borders. The pelitic unit that contains abundant amphibolite interlayers is gradational to a thick 150 m section of amphibolite which suggests a common source and origin. Most of the thicker layers, 3 to 250 m, probably represent dominantly flows and sills, and the thin 5 to 30 cm layers dominantly sills. In the Gravelly Range, east of the Ruby Range, a similar rock association exists in an area of greenschist-facies metamorphism. Greenstones with relict pillow structures are preserved (Bayley and James, 1973). The

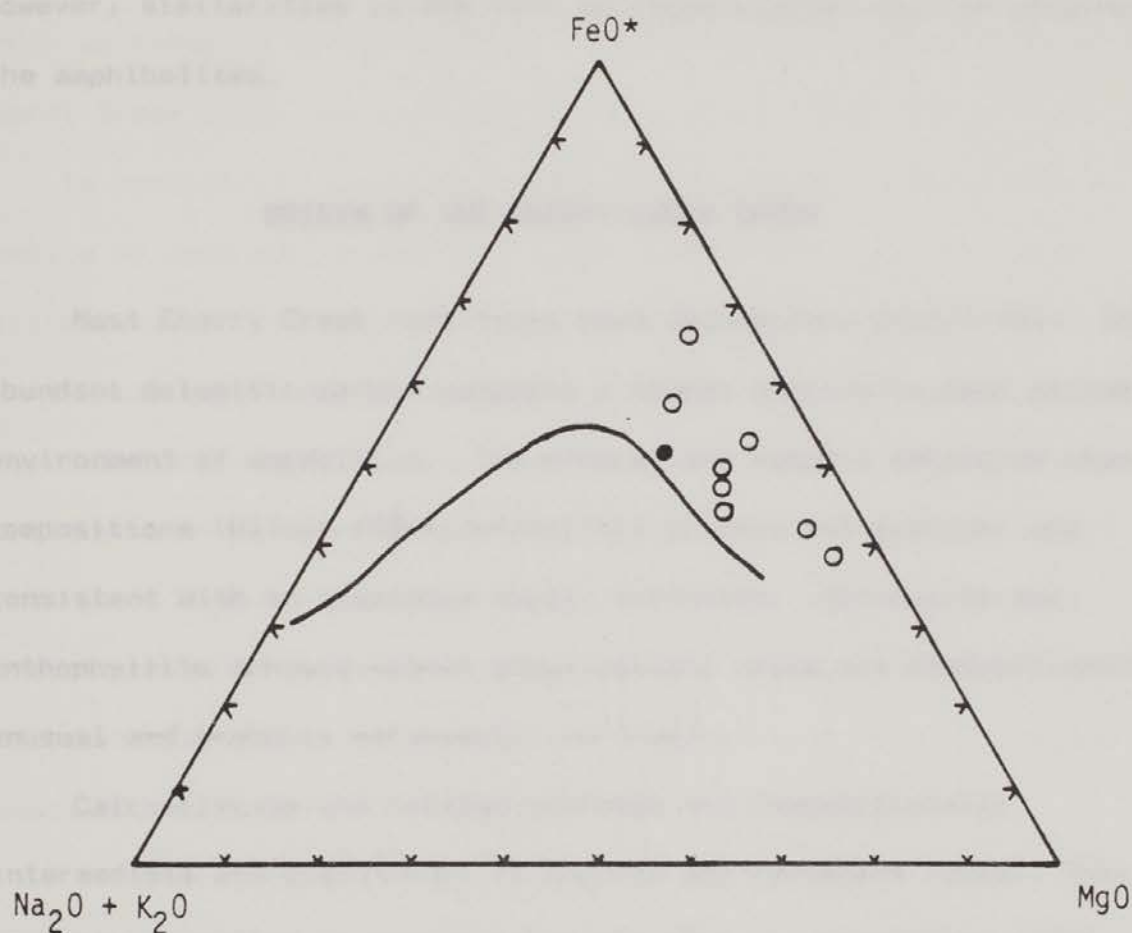


Figure 6. AFM plot of Cherry Creek Group amphibolites and similar amphibolites from the Tobacco Root Mountains, showing a tholeiitic trend. Open circles are plotted from data of Wilson (1981a) and the solid circle from Bielak (1978). FeO^* = total iron.

relationship of this sequence to that of the Ruby Range is unknown, however, similarities in the rock packages suggest similar origins for the amphibolites.

ORIGIN OF THE CHERRY CREEK GROUP

Most Cherry Creek rock types have sedimentary protoliths. The abundant dolomitic marble suggests a stable shallow to deep marine environment of deposition. The mineral and modally estimated chemical compositions (Wilson 1981a) of pelitic schists and gneisses are consistent with an aluminous shaley protolith. Actinolite and anthophyllite schists within these pelitic rocks are compositionally unusual and probably metasomatic in origin.

Calc-silicate and related gneisses are compositionally intermediate and gradational to pelitic and carbonate rocks. They were probably deposited as impure dolomites (Rcs-1), calcareous sands, and/or calcareous muds (Rcs-3, Rcs-4). Meta-quartzite and meta-conglomerates are minor. Composition and field relations suggest they were deposited as quartz sands, arkosic sands, calcareous sands, and arkosic conglomerates.

The rock package of the Cherry Creek Group resembles tectonically stable shelf/slope assemblages of quartzite, carbonate, and shale. In the Canadian Cordillera stable shelf sequence, basic flows and some pyroclastics were deposited in the outer parts of the shelf wedge; presumably near the continental rise-slope transition. They are most abundant near the carbonate-shale transition (Wheeler and Gabrielse,

1972). In the stable shelf sequence of the Great Basin, basaltic rocks occur as flows up to 300 m thick. Similarly, the amphibolites of the Cherry Creek Group are believed to be basaltic flows and sills.

In conclusion, the Cherry Creek Group probably accumulated as a shallow to deep marine shelf to slope sequence of dolomite, both siliceous and calcareous argillaceous sediments, and minor quartzitic and arkosic sands and conglomerates. Within this depositional sequence basaltic flows and sills, and minor chemically precipitated iron-formation and chert were also being deposited, possibly influenced from a nearby rift basin spreading center or island arc. The tholeiitic composition of these amphibolites, the sill origin of some of these amphibolites, and the lack of sediment contribution from an island arc source fits best with a rift environment.

DILLON GNEISS

The Dillon gneiss forms a concordant sheet 5 to 9 km thick (Garihan 1973) between the Cherry Creek and pre-Cherry Creek groups. It is fairly homogeneous in composition and texture. Numerous folded layers of amphibolite and marble are concordantly interlayered with the gneiss (figure 2). Thin marble units (5 to 200 m) continue for as much as 6 km along strike, and tend to parallel the regional structure outside the gneiss. Amphibolite forms pods that are as small as 1 by 5 m, and layers 1 to 200 m thick. Pods of ultramafic rock are scattered throughout the gneiss. They tend to be associated with the amphibolite layers, commonly in the crest of the larger F_1 folds. This occurrence has also been noted by Desmarais (1978), and is attributed to movement of these small competent units into areas of low stress. In addition to the marble, amphibolite, and meta-ultramafic rocks within the Dillon gneiss, interlayered thin layers and pods of semi-pelitic gneiss exist near the contact of the Cherry Creek Group.

The contact of the Dillon gneiss and Cherry Creek rocks is sharp and concordant (Okuma 1971, however, has reported finding discordant contacts). In one spot within the Sweetwater Pass study area, Dillon gneiss is found as a 15 to 20 m layer within a marble unit (figure 2). Similar interlayering of the Dillon gneiss and Cherry Creek rocks has been reported by other workers (Heinrich 1960, Okuma 1971) and is not confined to marble units as in the present study. Heinrich (1960)

believes that the total thickness of the Cherry Creek Group includes about 10% intruded Dillon gneiss.

The contact of the Dillon gneiss and the pre-Cherry Creek rocks is concordant with the two units interlayering over a wide area. The contact of the pre-Cherry Creek and Dillon gneiss units on figure 3 marks the western most mappable appearance of the Dillon gneiss. Heinrich (1960) and Okuma (1971) mapped several thick layers of Dillon gneiss within the pre-Cherry Creek gneisses in the southeastern part of the range.

Structure in the Dillon gneiss is similar to that in the Cherry Creek rocks, suggesting that they have been deformed together. F_1 folding appears as mesoscopic isoclinal folds in banded gneisses. This folding event is also represented by less obvious megascopic isoclinal folds best seen within the sequences of interlayered Dillon gneiss, amphibolite, semi-pelitic gneiss, and ultramafic rock near the contact of the Cherry Creek rocks. F_2 folding is represented by large open folds, best seen folding the thin layers of amphibolite and marble.

Gneisses of the Dillon gneiss unit include:

- Quartz-feldspar gneiss
- Biotite gneiss
- Garnet gneiss
- Garnet Hornblende gneiss

- Semi-pelitic gneiss

These gneisses, excluding the semi-pelitic gneisses, are fairly homogeneous in composition, having only slight variations in mafic mineral abundances (see table 7). A study by Garihan and Williams (1976), on the Dillon gneiss, revealed heterogeneities not emphasized

in this study. These may be partly due to the presence of pegmatitic rocks and layers of sedimentary semi-pelitic gneisses not separately considered within their data.

Quartz-feldspar Gneiss

Quartz-feldspar gneisses are the most abundant rock type in the Dillon gneiss. Most contain less than 3% mafic minerals. Less common varieties contain up to 8% mafic minerals, including garnet, biotite, hornblende, and iron oxides. Table 7 gives the estimated modal abundances for several of these gneisses. Figure 7 is a quartz-plagioclase-potassium feldspar plot of these gneisses. This plot shows the composition of these gneisses to be within the granite field of the I.U.G.S. classification scheme.

Outcrops of quartz-feldspar gneiss tend to be rounded and have high relief. Slight metamorphic layering was isoclinally folded during F_1 deformation. Layering, where present, ranges from 1 mm to 10 cm and is dominated by pink to grey quartz and feldspar alternating with layers of quartz, feldspar, and minor mafic minerals. Shearing during deformation may have aided in developing this layering.

These rocks show varying degrees of metamorphic textural development from nearly massive to highly foliated and even lineated types. Micas and flattened and elongate quartz crystals define the foliation. Lineations are common in the gneisses near the Dillon gneiss-Cherry Creek Group contact. They were produced by tectonic deformation that in some cases created a mylonitic texture.

Table 7. Modal analyses of the Dillon quartz-feldspar gneisses;
 Rqf & Dqf=quartz-feldspar gneiss, Rbg=biotite-quartz-feldspar
 gneiss, Rgg=garnet-quartz-feldspar gneiss, Rhg=hornblende-
 quartz-feldspar gneiss.

Sample #	Rqf-2a	Rqf-6	Rqf-7	Rqf-7a	Dqf-3	Dqf-4	Dqf-5	Rbg-1	Rgg-3	Rhg-4
Plagioclase	13	20	18	30	30	14	35	15	32	28
Quartz	35	30	35	24	28	34	25	30	30	35
Potassium Feldspar	38	47	38	45	40	50	36	40	25	30
Biotite	--	--	<1	tr	2	--	2	5	--	--
Muscovite	<1	tr	<1	tr	--	--	--	<1	<1	--
Hornblende	--	--	--	--	tr	--	--	--	--	3
Garnet	2	--	2	<1	--	--	<1	--	6	1
Iron oxide	1	2	--	1	<1	--	tr	tr	2	2
Zircon	tr	tr	tr	tr	tr	--	tr	tr	--	tr
Apatite	--	--	--	--	tr	tr	tr	tr	--	tr
Rutile	tr	--	--	--	--	--	--	--	--	--
Allanite	--	--	--	--	tr	--	tr	<1	--	--
Chlorite	<1	1	tr	--	--	1	--	tr	--	--
Epidote	2	--	tr	--	--	tr	--	<1	--	--
Sericite	7	tr	7	tr	<1	1	1	10	5	1
Hematite	1	tr	tr	tr	tr	--	tr	--	tr	tr

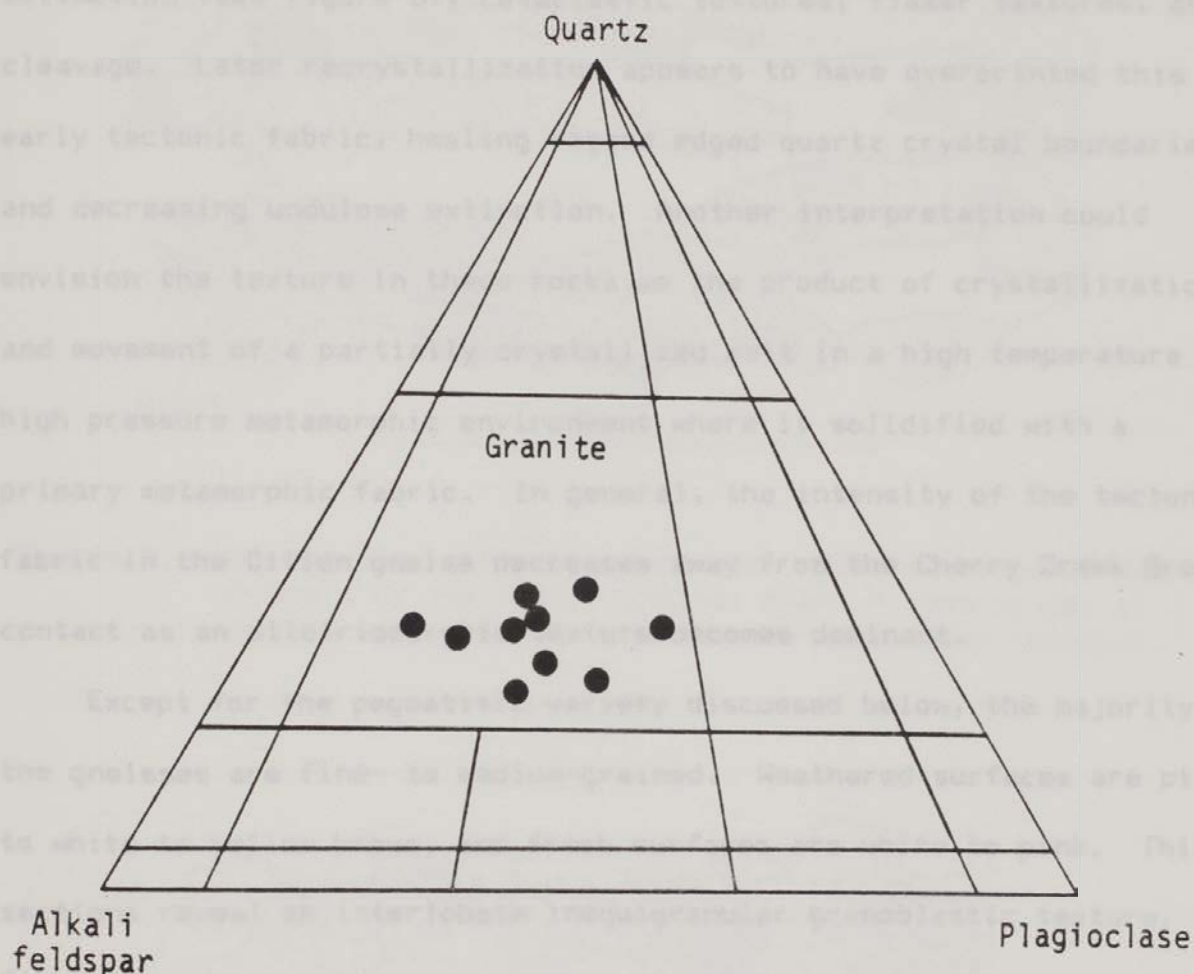


Figure 7. Quartz-plagioclase-alkali feldspar plot of the Dillon gneisses. All plot in the granite field of the I.U.G.S. classification scheme.

Deformation also produced elongate quartz crystals with strong undulose extinction (see figure 8), cataclastic textures, flaser textures, and cleavage. Later recrystallization appears to have overprinted this early tectonic fabric, healing ragged edged quartz crystal boundaries and decreasing undulose extinction. Another interpretation could envision the texture in these rocks as the product of crystallization and movement of a partially crystallized melt in a high temperature and high pressure metamorphic environment where it solidified with a primary metamorphic fabric. In general, the intensity of the tectonic fabric in the Dillon gneiss decreases away from the Cherry Creek Group contact as an allotriomorphic texture becomes dominant.

Except for the pegmatitic variety discussed below, the majority of the gneisses are fine- to medium-grained. Weathered surfaces are pink to white to yellow brown, and fresh surfaces are white to pink. Thin sections reveal an interlobate inequigranular granoblastic texture, figure 9.

These gneisses include pegmatitic varieties (sample Rqf-7) that form concordant foliated sheets and pods. The length of these bodies rarely exceeds 3 km (Okuma 1971). Quartz commonly has a graphic texture, which is very conspicuous in hand sample. Deformation produced cataclastic texture in some of the feldspars. The mineral composition of these pegmatitic gneisses is similar to the other gneisses and is given in table 7, sample Rqf-7. Heinrich (1960) described an unusual body that contains dumortierite, perthite, quartz, oligoclase, muscovite, and tourmaline. A younger group of pegmatites

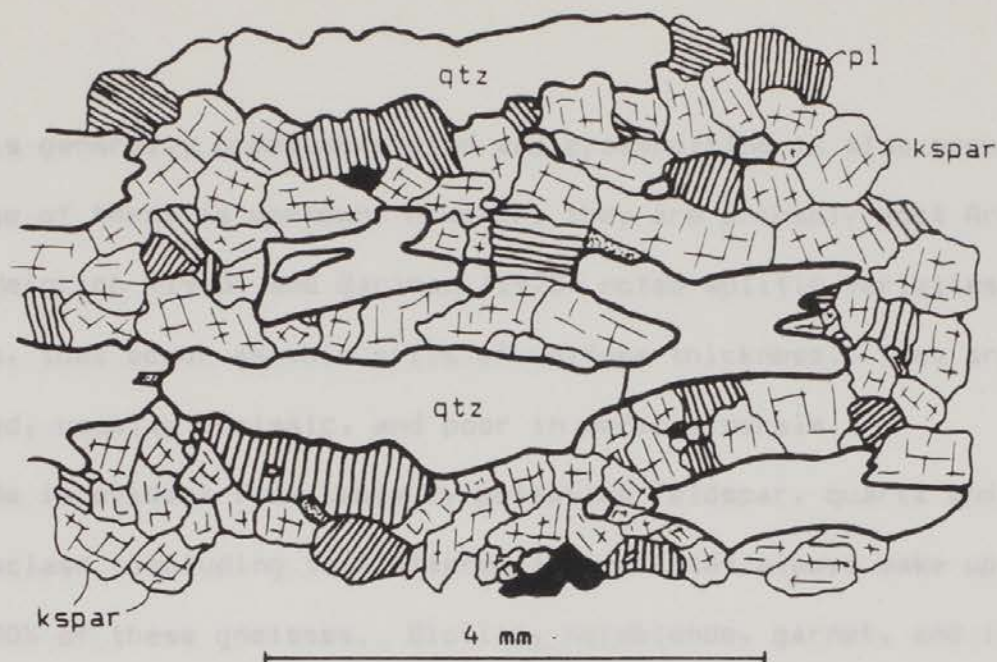


Figure 8. Thin section showing deformation related elongated quartz crystals of the Dillon gneiss; black = iron oxide, pl = plagioclase, qtz = quartz, kspar = potassium feldspar.

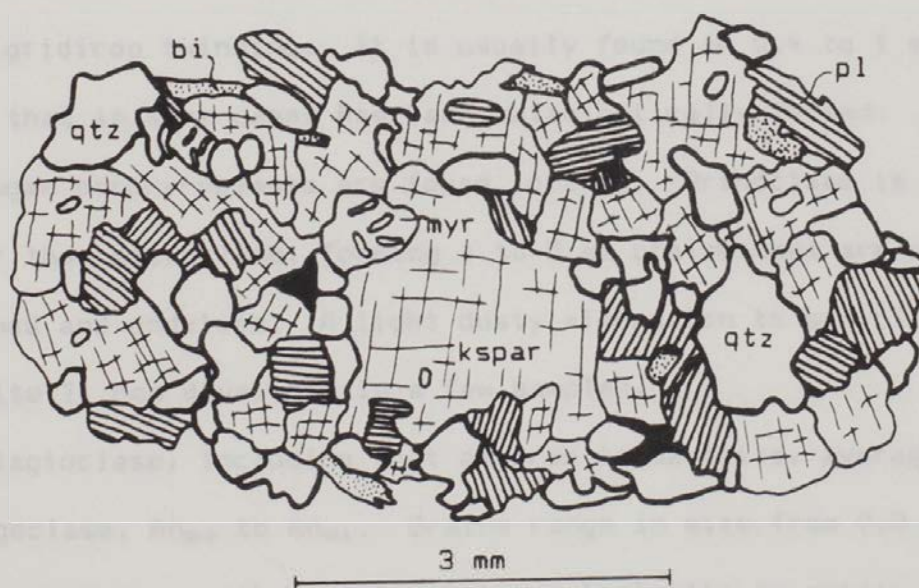


Figure 9. Thin section showing granoblastic texture of the Dillon gneiss. Note the myrmekite (myr); pl = plagioclase, qtz = quartz, kspar = potassium feldspar, bi = biotite.

that is generally unmetamorphosed and crosscutting is also present. The age of these is unknown, however, they are probably post Archean.

Heinrich (1960) and Garihan (1973) noted aplitic varieties of gneiss, that occur as thin sills of uniform thickness. They are fine grained, usually gneissic, and poor in mafic minerals.

As is evident from table 7, potassium feldspar, quartz and plagioclase (including that altered to sericite) always make up greater than 90% of these gneisses. Biotite, hornblende, garnet, and iron oxide are common accessory minerals.

Potassium feldspar is the most abundant mineral in all of the quartz-feldspar gneisses, averaging 39%. Both orthoclase and microcline are present, commonly in the same sample. String, vein, and braid perthite is frequently encountered. Microcline is distinguished by its gridiron twinning. It is usually found as 0.4 to 1 mm anhedral grains that in some cases has been cataclastically formed. Large, 2 to 3 cm augen porphyroblasts are found locally. Orthoclase is generally coarser than microcline, forming 1 to 5 mm grains that are commonly flattened and undulose. A light dusty alteration to sericite and kaolinite(?) has developed in a few samples.

Plagioclase, including that altered to sericite, averages 27%. It is oligoclase, An_{20} to An_{31} . Grains range in size from 0.2 to 3 mm, with some of the smaller grains being cataclastic in origin. Thin rims of more sodic plagioclase are present in some samples, reverse zoning in others. In one sample, Rqf-7a, the anorthite content ranges from An_{25} to An_{31} from core to rim, creating reverse zoning. Antiperthite

was noted in sample Dgg-5, where potassium feldspar exists as inclusions parallel to the albite twinning. Myrmekite was found in samples Dgg-3 and Rbg-1 (see figure 9). Alteration to sericite and locally epidote is common. In some samples sericite makes up one third of the plagioclase.

Quartz averages 30%. It occurs as small 0.2 to 0.6 mm irregular undulose grains, and as 0.5 to 1.5 mm by 3 to 8 mm undulose flattened and stretched grains (figure 8). These larger grains are in highly deformed rocks. They are flattened parallel to foliation. In hand sample it is evident that these quartz grains are highly lineated. Inclusions of microcline exist.

Biotite, where present, is minor in amount, and is in some cases entirely altered to green chlorite. It is pleochroic from yellow to red brown, fine-grained (0.2 to 0.4 mm), and defines a foliation. Garnet is present in minor amounts. It occurs as 0.4 to 4 mm pale pink porphyroblasts. They are in some cases slightly flattened and commonly contain inclusions of biotite and iron oxides that parallel the foliation.

Sample Rghg-4a is a gneiss that contains minor hornblende. Although no other gneisses containing substantial hornblende were found in this study, Garihan (1973) and Garihan and Williams (1976) have described biotite hornblende gneisses, garnet hornblende gneisses and hornblende biotite gneisses within the Dillon gneiss and state that these rock types are common, but not abundant. In all cases hornblende is minor. It is pleochroic from pale green to olive green and is

concentrated in layers, where it defines a foliation.

Zircon, a common trace mineral, is dominantly subhedral but varies from anhedral partly rounded and elongate grains to euhedral stubby prismatic crystals.

Semi-pelitic Gneiss

Semi-pelitic gneisses contain appreciable amounts of sillimanite, garnet and biotite. They also contain less potassium feldspar and in some samples more plagioclase than the gneisses described above. Gneiss types within this category include biotite-sillimanite-garnet gneiss and garnet-sillimanite-biotite gneiss. Mineral content suggests protoliths of shale and muddy sandstones. Table 8 gives the estimated modal abundances for some of these gneisses.

Semi-pelitic gneisses were found only in the Sweetwater Pass study area. The extent and shape of outcrop for these gneisses is difficult to determine. However, it appears that they form thin layers (1 to 3.5 m) that continue for only short distances. The layers appear to have a consistent field association in which they are concordantly interlayered and folded with amphibolite and quartz-feldspar gneiss on a meter scale. In places the semi-pelitic gneisses contain F_1 isoclinally folded quartz and feldspar veins 1 to 4 cm wide. As can be seen in table 8 the composition of these gneisses is variable.

Plagioclase varies from 16% to 53%. The anorthite content is An_{20} to An_{23} in the gneisses containing potassium feldspar, and An_{30} to An_{31} in the samples containing no potassium feldspar. Crystals are anhedral, granoblastic, 0.4 to 1mm, and commonly albite twinned. One

Table 8. Modal analyses of semi-pelitic gneisses within the Dillon gneiss; Rbsgg=biotite-sillimanite-garnet-gneiss, Rgsbg=garnet-sillimanite-biotite gneiss

Sample #	Rbsgg-5	Rgsbg-1	Rgsbg-2	Rgsbg-2b
Plagioclase	38	16	53	40
Quartz	20	18	20	1
Potassium Feldspar	--	10	--	20
Biotite	2	40	12	25
Muscovite	tr	1	tr	tr
Sillimanite	10	8	8	10
Garnet	15	5	6	1
Iron oxide	3	2	<1	--
Zircon	--	tr	tr	tr
Apatite	--	--	--	tr
Rutile	1	--	tr	tr
Graphite	1	--	--	--
Chlorite	--	--	--	tr
Epidote	--	--	tr	tr
Sericite	10	--	3	3
Hematite	--	tr	tr	--

sample (Rgsbg-2) contains some larger (3 mm) undulose and locally bent crystals that are probably relic pre-metamorphic crystals.

Potassium feldspar exists in sample Rgsbg-1 as orthoclase and in Rgsbg-2b as gridiron twinned microcline. These feldspars occur as 0.1 to 0.2 mm interstitial grains and as larger 1 to 2.5 mm grains. They are commonly undulose and perthite is present in both samples. Quartz varies from 1 to 20% and forms irregular grains from .1 to 3 mm.

Biotite varies from 2% to 40%. It is found as pleochroic yellow to red brown fine-grained crystals concentrated in mafic layers, and defines a strong foliation. Garnet makes up between 1 and 15% of each sample. It is pale pink, probably almandine, the common garnet in rocks of this composition. It occurs as 2 to 10 mm poikiloblastic porphyroblasts, in some cases slight flattened.

Sillimanite exists in every sample, making up 8 to 10% of the total rock. It occurs as buff weakly pleochroic, diamond shaped cross-sections, and elongate needles. End sections are 0.2 to 0.4 mm and elongate crystals average 1 mm in length. One sample (Rbsgg-5) contains scattered 2 by 4 mm pods of sillimanite crystals. In most samples, sillimanite is more evenly distributed in mafic layers.

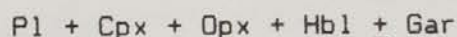
Amphibolite

Amphibolites exist as concordant pods and layers folded and interlayered with gneisses throughout the Dillon gneiss unit. Meta-ultramafic pods are commonly associated with the amphibolite layers. These amphibolites differ from those of the other units in mineral

content and field characteristics; however, they probably have similar basaltic protoliths.

Unlike the pre-Cherry Creek and Cherry Creek group amphibolites these are layered in places and veined with plagioclase segregations that contain large clinopyroxene crystals (up to 1 cm). These amphibolites are reddish brown on weathered surfaces, gray on fresh surfaces, and lack the characteristic "salt and pepper" appearance of the pre-Cherry Creek and Cherry Creek amphibolites.

Table 9 gives the mineral abundances for several of these amphibolites, and figure 10 is a ACKFm plot of these rocks. The assemblage:



is a granulite facies mineral assemblage characteristic of these amphibolites. This maybe a result of metamorphism in a relatively dry environment, rather than under true granulite facies temperatures and pressures, which would be higher than those indicated by the surrounding rocks.

In thin section plagioclase is seen to be the dominant mineral with hornblende, diopside, hypersthene, and in one sample (RA-40) garnet, each making up sizable portions of the remaining rock. Segregations of light and dark minerals are present in some samples, however, a fine- to medium-grained massive granoblastic texture is dominant. Strained grains are common and a weak cataclastic texture is locally developed. Veins composed of plagioclase that contain large (up to 1 cm) diopside crystals are commonly present.

Table 9. Modal analyses of amphibolites in the Dillon gneiss

Sample #	Rhg-4a	RA-39	RA-40	RA-41	RA-42	RA-43
Plagioclase	55	50	30	49	48	53
Hornblende	21	28	20	30	30	27
Diopside	16	15	25	11	8	8
Hypersthene	6	4	4	6	8	10
Garnet	--	--	15	--	--	--
Quartz	--	2	2	1	4	1
Potassium feldspar	--	1	1	--	1	--
Biotite	--	--	--	1	--	--
Iron oxide	2	1	3	2	1	1
Apatite	tr	tr	--	tr	tr	tr
Zircon	tr	--	tr	--	tr	tr
Sericite	tr	tr	tr	tr	--	--
Hematite	tr	--	tr	--	tr	tr

Figure 10. ACF diagram of amphibolites in the Dillon gneiss showing granulite grade mineral assemblages. Pl = plagioclase, Di = diopside, Hst = hypersthene, Gr = garnet.

Plagioclase is andesine or labradorite, $An_{30}-An_{50}$. Grain size ranges from 0.2 to 1.5 mm within each sample. Reverse zoning was found in one sample (RA-40) and slight normal in another (RA-43). Strain produced bent grains, undulose extinction, and cataclastic texture.

Hornblende is pleochroic from yellow to light brown and ranges in size from .1 to 3 mm. Pyroxene crystals with rims of hornblende along with gradational and unstable contacts of these minerals, figure 11, suggest hornblende is altering from pyroxene, possibly as a retrograde reaction.

Diopside is generally more abundant than hypersthene. These minerals are generally found as fine grains from 0.1 to 0.6 mm, however, locally 1 to 1.5 mm crystals exist. Crystals of diopside up to 1 cm are common in plagioclase veins. Hypersthene is colorless to very pale brown and is lighter colored than diopside which is slightly pleochroic from pale brown to pale green.

ORIGIN OF THE DILLON GNEISS

The origin of granitic gneiss has been a controversy for years. Butler (1969) summarized the basic models that are favored for the origin of granitic gneiss. These include,

- 1) Sedimentary-volcanic depositional model. Granitic gneiss results from the metamorphism of depositional sequences of sedimentary rocks, or volcanic rocks, with little change in original composition.

- 2) Magmatic model. The granitic rock results from the crystallization of a silicate melt intruded into older rock, mainly

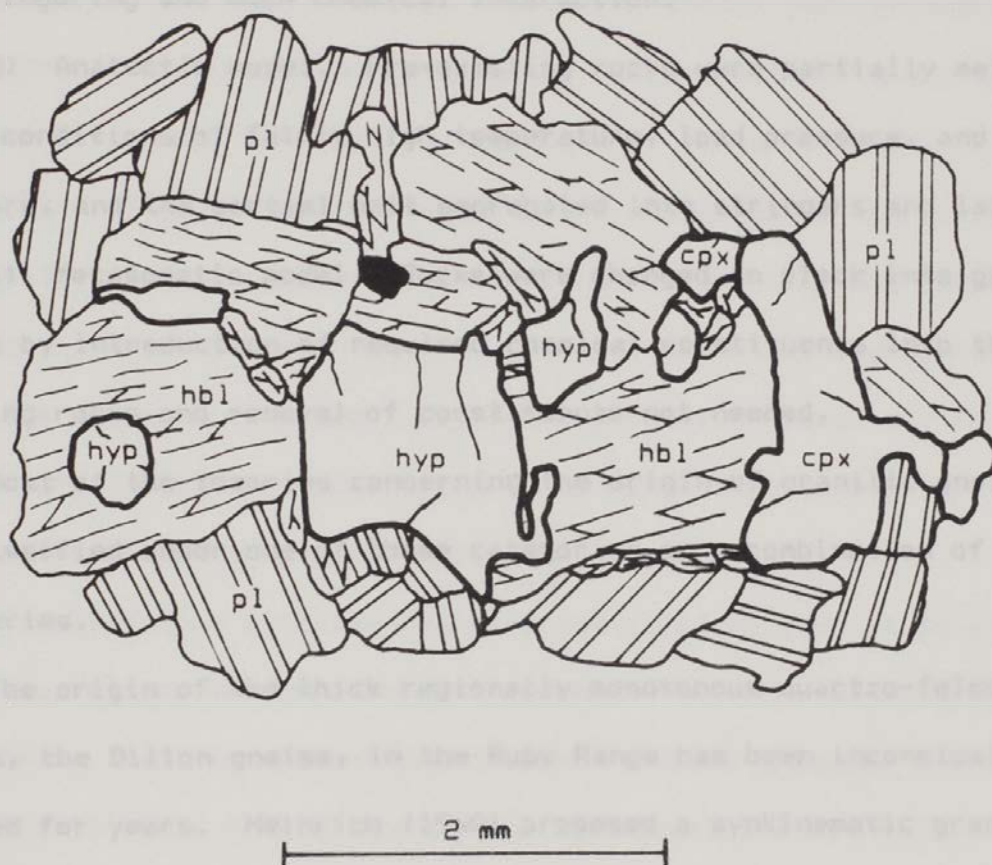


Figure 11. Thin section of amphibolite in the Dillon gneiss showing hornblende surrounding hypersthene. Hornblende may be altering from hypersthene as a retrograde reaction. Black is iron oxide, hbl = hornblende, hyp = hypersthene, cpx = diopside-salite, and pl = plagioclase.

along planes of bedding or schistosity, with intricate mechanical interfingering and much chemical interaction.

3) Anatectic model. Pre-existing rocks were partially melted under conditions of fairly high temperature, load pressure, and water pressure, and the partial melt segregated into stringers and layers.

4) Metasomatic model. Rocks were changed in place into granitic gneiss by introduction of required chemical constituents into the pre-existing rocks and removal of constituents not needed.

Most of the theories concerning the origin of granitic gneiss can be classified under one of these categories or a combination of these categories.

The origin of the thick regionally monotonous quartzo-feldspathic gneiss, the Dillon gneiss, in the Ruby Range has been inconclusively debated for years. Heinrich (1960) proposed a synkinematic granitic intrusive origin. Smith (1980) and Okuma (1971) also favored a plutonic origin. Garihan and Okuma (1974) and Garihan and Williams (1976) argued for a sedimentary origin and suggested possible protoliths as arkosic rock, or mudstone/siltstone rich in illite and quartz(?). Later, Garihan (1979) equally accepts the possibility of a synkinematic pluton or a sedimentary protolith for the Dillon gneiss. James and Hedge (1980) favor a multiple origin with some of it being sedimentary, some igneous, and some remobilized basement rock. Wilson (1981a) suggests a sedimentary and volcanic sequence as a protolith. Although most workers, including the author, support one of these origins, they also admit that both sedimentary and igneous protoliths

are possible.

Several characteristics of the Dillon gneiss such as concordant contacts, interlayered amphibolite and marble, lack of skarn associated with marble, associated pegmatites, lack of contact effects or evidence of a disruptive intrusion, compositional homogeneity, and granitic composition have been used as evidence of sedimentary and igneous origins. In many cases, the same characteristic has been interpreted in different ways to support different origins. Almost all these characteristics of the Dillon gneiss can be rationalized by both a sedimentary/volcanic metamorphic, or plutonic origin.

Consideration of these characteristics along with 1) an evaluation of the origin of the gneisses by looking at the rock association (including the Cherry Creek and pre-Cherry Creek groups), 2) its possible tectonic origin, and 3) making comparisons with other similar gneisses in which an origin is better known, leads me to favor a synkinematic intrusive origin for much of the gneisses. Infrequent consistent layering of semi-pelitic gneiss, quartz-feldspar gneiss and amphibolite suggests some of the gneiss is also sedimentary or volcanic in origin. Most likely, both sedimentary or volcanic, and intrusive granite make up the Dillon gneiss.

Deformation and metamorphism destroyed any primary igneous or sedimentary textures that may have been present in these gneisses. Slight layering may be the result of metamorphism and deformation rather than an original sedimentary feature.

Concordant contacts and the lack of contact effects for the Dillon

gneiss have been used as evidence of a sedimentary origin. However, this need not be the case. Buddington (1959) observed that deeply emplaced synkinematic intrusions are characteristically concordant to their country rock. Similarly, studies in the Coast Plutonic Complex of British Columbia (Hutchison, 1982), one of the best sections of exposed lower crust in which deep plutonic features can be studied, have shown that concordant contacts are common. These studies also show that these deep intrusions intrude passively.

Several Archean high-grade terrains contain concordant intrusive granitic rock (Wilson 1972, McGregor 1973, Janardhan et al 1977). In fact, review of the literature shows concordant contacts to be just as common as discordant ones. McGregor (1973), describing plutonic gneisses in the Godthab district of West Greenland, stated that intense strain deformation was sufficient to rotate earlier structures until they became parallel, also that many originally discordant contacts are now concordant. Wilson (1972) believes that the interface between basement and cover was an important control for the concordant sheet intrusions of granitic rock in the Rhodesian Archean craton. Strong deformation occurred in the Ruby Range and intrusion control may have occurred along the Cherry Creek-Pre-Cherry Creek contact. These processes may have contributed to the concordancy of the Dillon gneiss.

The presence of interlayered amphibolite is easily explained by sedimentary, volcanic, and plutonic processes of origin for the Dillon gneiss. In sedimentary and volcanic sequences they may represent basaltic flows and tuffs or possibly sills. The abundant amphibolite

in granitic plutonic rocks is either basaltic dikes and sills, or inclusions of the country rock. Some of the amphibolites in the Dillon gneiss may have originated as basaltic flows as part of the Cherry Creek Group, which were later included in the Dillon gneiss as inclusions and layers within and between sheets of intruded granite. Figures 5 (p. 27) and 10 (p. 48) are ACKFm plots of the amphibolites from the Cherry Creek Group and Dillon gneiss, respectively.

Comparison of these plots shows that although the stable mineral assemblages are different, upper amphibolite for the Cherry Creek and granulite for the Dillon gneiss, the location of the samples within the diagram are very close. Thus, the difference in mineral composition between the amphibolites of the Cherry Creek Group and those of the Dillon gneiss (compare tables 6 and 9) appears to be due more to differences in the conditions of metamorphism rather than of composition. However, this conclusion awaits chemical evaluation.

It is possible that these amphibolites are sills. If so, they were injected before or during deformation and folded with the gneiss during deformation. Synplutonic basaltic dikes are abundant in many deep-seated granitic batholiths such as the Idaho batholith (Hyndman, 1985), amounting to as much as 20% of the batholiths volume (Foster, 1986). Amphibolites within granitic gneisses in other Archean terrains have been interpreted as dikes in some areas (McGregor, 1973) and as inclusions in others (Glikson, 1984). Especially common as xenoliths are mafic-ultramafic associations similar to that found here (Glikson, 1984).

The presence of marble as long thin layers within the Dillon gneiss has been interpreted by Garihan and Williams (1976) as evidence of a sedimentary origin for the gneisses. They believe that the lack of skarn and the fact that the marbles are traceable for several kilometers along strike rule out any thing but the most passive origin for the Dillon gneiss. Thus, rather than calling upon a passive intrusion they favor a sedimentary origin. A passive intrusion, which is common for deep level plutons, is possible for the Dillon gneiss. The marble units, like amphibolites and semi-pelitic gneisses, may be layers and fragments of the Cherry Creek rocks separated from the main body by intrusion of the Dillon gneiss. In deep dry intrusions where little or no geothermal or fluid gradient between intrusion and host rock is present, skarn formation would not be expected.

Garihan and Williams (1976) appeal to compositional similarity in proposing an arkosic protolith. However, because marbles and arkoses make up a rather unusual rock package, they alternately call upon a mudstone or siltstone rich in illite and quartz(?) as a protolith. Wilson (1981a) supports these proposed protoliths and suggests that rhyolitic volcanics may also be present. I consider these protoliths improbable for much of the gneisses because: 1) sedimentary bedding, structures, and conglomerate beds are commonly preserved in high grade rocks and have not been found in the Dillon gneiss, 2) volcanic structures or breccias that could survive high grade metamorphism have not been found and, 3) the homogeneous composition, although possible with both volcanic and sedimentary origins, is more consistent with an

igneous origin.

The rock package association is not as compatible with a sedimentary or volcanic origin as with a plutonic origin. Review of the literature on Archean rocks shows: 1) meta-arkose and marble are an unusual and uncommon rock package, 2) marbles tend to be rare in greenstone belts, where Archean felsic volcanic rocks are commonly found, and 3) the only sequences of rocks that marble is commonly found in are very similar to the Cherry Creek Group. In several Archean high-grade terrains fragments of supracrustal sequences like the Cherry Creek Group are found within plutonic gneisses (McGregor 1973, Neves et al 1982).

Figure 12 is a quartz-albite-orthoclase ternary plot of the Dillon gneiss (excluding the semi-pelitic gneisses). The composition of the Dillon gneiss falls near the ternary minimum, showing that the composition of the Dillon gneiss is that of a melt that would be expected to form at the assumed P_{H_2O} conditions of 4 to 8 kbars. Corrections have been made for the albite component in potassium feldspar using the chart given by Deer et al (1963, p. 52), and the orthoclase component in plagioclase using tables of similar plagioclase analysis in Deer et al (1963, p. 112-113). A P_{H_2O} of 4 to 8 kbars is used on the assumption that P_{H_2O} equals load pressure. The metamorphic section contains discussion on the known pressure, 4 to 8 kbars, of metamorphism.

Comparison of Figures 7 (p. 38) and 13 (p. 63), quartz-plagioclase-potassium feldspar plots of the Dillon gneiss and pre-

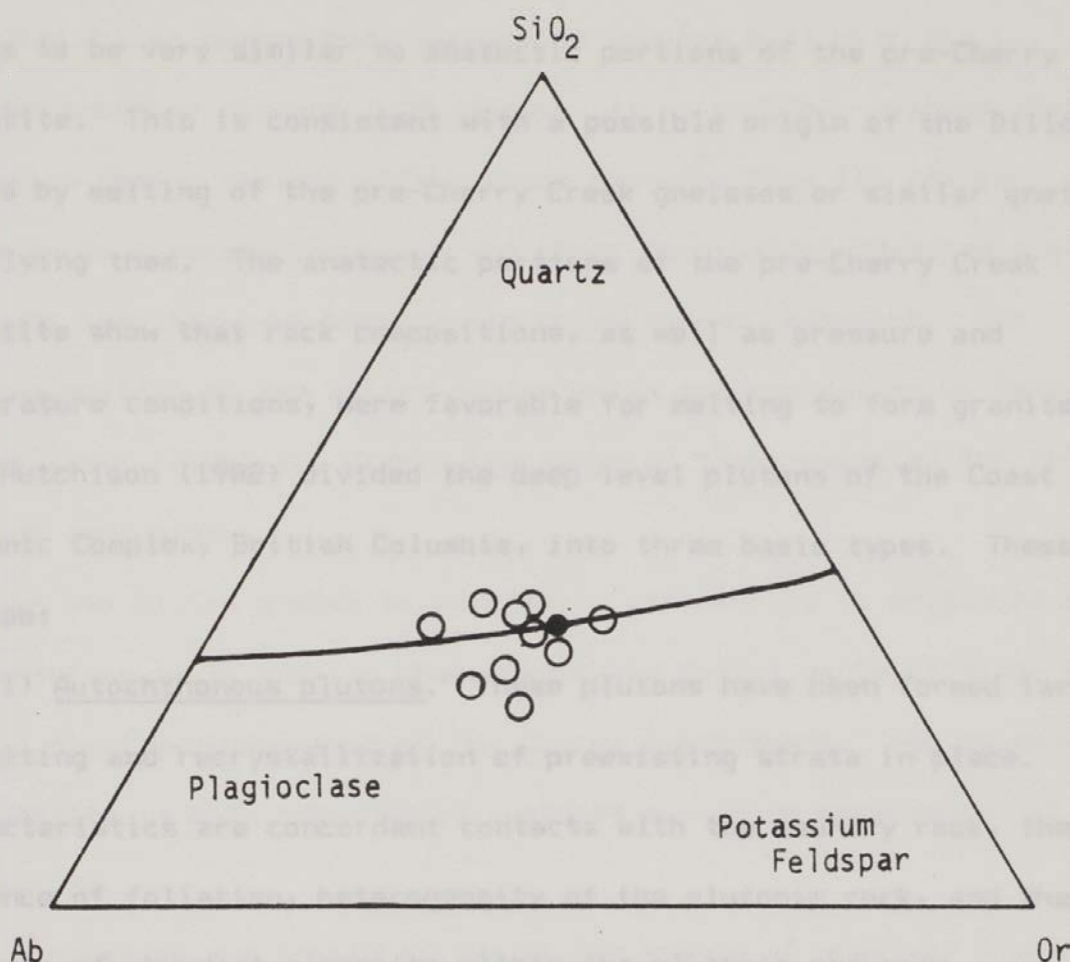


Figure 12. Quartz-albite-orthoclase plot of the Dillon gneisses. The solid circle is the estimated ternary minimum of this system for an anorthite content of 25 and pressures of 5 to 7 kbars. Taken and modified from Luth (1976).

Cherry Creek gneisses respectively, shows the composition of the Dillon gneiss to be very similar to anatectic portions of the pre-Cherry Creek migmatite. This is consistent with a possible origin of the Dillon gneiss by melting of the pre-Cherry Creek gneisses or similar gneisses underlying them. The anatectic portions of the pre-Cherry Creek migmatite show that rock compositions, as well as pressure and temperature conditions, were favorable for melting to form granite.

Hutchison (1982) divided the deep level plutons of the Coast Plutonic Complex, British Columbia, into three basic types. These include:

1) Autochthonous plutons. These plutons have been formed largely by melting and recrystallization of preexisting strata in place. Key characteristics are concordant contacts with the country rock, the presence of foliation, heterogeneity of the plutonic rock, and the presence of abundant migmatite within the plutonic sequence.

2) Parautochthonous plutons. These are plutons that show movement but have not traveled far from their origin. Characteristics of these plutons include; concordant contacts in many areas, the presence of foliation, the lack of pervasive and dominant migmatite, and the dominance of fairly homogeneous plutonic rock that grades laterally into migmatized sections of country rock.

3) Allochthonous plutons. These plutons moved considerable distances from their origin. They are usually smaller and shallower than the other two types. They are generally discordant to the country rock, more homogeneous and have less of a metamorphic texture than the

above types.

The Dillon gneiss body appears to compare best with the parautochthonous plutons. If igneous, it is probably a sheet like intrusion that travelled only a short distance from its source. The presence of a strong foliation and shear deformation features suggest that the body may have been partly solid during intrusion. The heterogeneities of the Dillon gneiss which are emphasized by Garihan and Williams (1976) are within the range of those expected for this type of intrusion.

If the Dillon gneiss is dominantly sedimentary in origin it may represent an early clastic phase deposited during early rifting, before stable shelf sedimentation of the Cherry Creek Group. The abundant amphibolite in both these units supports a rifting environment of deposition.

I consider the origin of the Dillon gneiss an unsolved problem, however, I do believe both sedimentary and granitic intrusive rocks are present in the gneiss. I favor a deep synkinematic plutonic origin for much of the gneiss. Intrusion may have been partly controlled by the Cherry Creek/pre-Cherry Creek contact. During intrusion, inclusions and layers of amphibolite, semi-pelitic gneiss, marble and meta-ultramafic rock, which originated as part of the Cherry Creek Group, may have been incorporated within and between sheets of intrusive granite. Also incorporated between sheets of granite may have been arkoses or siltstone, however, I believe this minor in comparison to plutonic gneiss.

PRE-CHERRY CREEK GROUP

Outcrops of the pre-Cherry Creek rocks exist in the southeastern and east-central parts of the Ruby Range (figure 1). The pre-metamorphic thickness of the unit is unknown because it is fault bounded on the east, and because of unknown structural transposition within the unit. A two kilometer section of these rocks was studied, figure 3. Rock types in this section include:

- 1) Biotite and Garnet-Biotite-Quartz-Feldspar Gneiss
- 3) Garnet-Sillimanite-Biotite-Quartz-Plagioclase Gneiss
- 4) Hornblende Gneiss and Hornblende-Biotite Gneiss
- 5) Amphibolite

Table 10 gives representative estimated modal abundances for these gneisses, and figure 13 is a quartz-plagioclase-potassium feldspar plot of these gneisses. The contact between the pre-Cherry Creek gneisses and Dillon gneiss is concordant with the two interlayering over a broad area. The contact on figure 3 marks the western most mappable appearance of the Dillon gneiss. Within 0.5 to 1 km of this contact Dillon gneiss is dominant. The zone of gradation consists of veins and layers of Dillon gneiss from 1 cm to several meters wide alternating with layers and patches of pre-Cherry Creek biotite gneiss. The pre-Cherry Creek gneisses are compositionally variable and continue for only short distance along strike. Because of this, the rock types were not mapped individually but as generalized groups defined by the

Table 10. Modal analyses of pre-Cherry Creek gneisses; FBG=fine grained biotite-quartz-plagioclase gneiss, CBG=coarse biotite quartzofeldspathic gneiss

Sample #	FBG-1	FBG-2	FBG-7	CBG-2	CBG-3a	CBG-3b	CBG-4
Plagioclase	58	50	67	19	14	20	21
Quartz	34	30	20	30	35	33	30
Potassium Feldspar	1	10	1	45	50	40	41
Biotite	tr	tr	10	1	tr	4	3
Hornblende	--	--	--	--	--	--	--
Sillimanite	--	--	tr	--	--	--	--
Garnet	--	--	--	--	--	--	--
Iron oxide	<1	1	<1	--	tr	1	tr
Zircon	tr	tr	tr	--	--	tr	<1
Apatite	--	tr	tr	tr	--	tr	tr
Rutile	--	--	--	--	--	--	--
Tourmaline	--	--	--	--	--	--	--
Calcite	--	--	--	--	--	--	--
Chlorite	5	5	<1	<1	tr	tr	1
Epidote	--	1	--	<1	tr	--	--
Sericite	2	5	2	3	1	2	4
Hematite	--	--	tr	--	--	tr	--

Table 10. (cont) Quartz plagioclase gneisses; BGG=biotite-garnet gneiss, SG=garnet-sillimanite-biotite gneiss, HG=hornblende gneiss, HBG=hornblende-biotite gneiss.

Sample #	BGG-1	SG-1	SG-3	HG-1*	HG-3	HBG-2
Plagioclase	63	44	40	45	47	48
Quartz	20	40	40	15	7	29
Potassium Feldspar	--	--	--	--	--	1
Biotite	7	5	7	--	1	tr
Hornblende	--	--	--	40	43	7
Sillimanite	--	4	6	--	--	--
Garnet	4	4	3	--	--	--
Iron oxide	1	2	4	--	<1	<1
Zircon	<1	tr	tr	--	tr	tr
Apatite	tr	--	--	--	--	--
Rutile	--	<1	tr	--	--	--
Tourmaline	--	--	--	--	--	tr
Calcite	--	--	--	--	tr	--
Chlorite	--	--	--	--	<1	10
Epidote	--	--	--	--	tr	2
Sericite	--	1	--	--	1	2
Hematite	tr	tr	--	--	--	tr

* Hand sample estimation

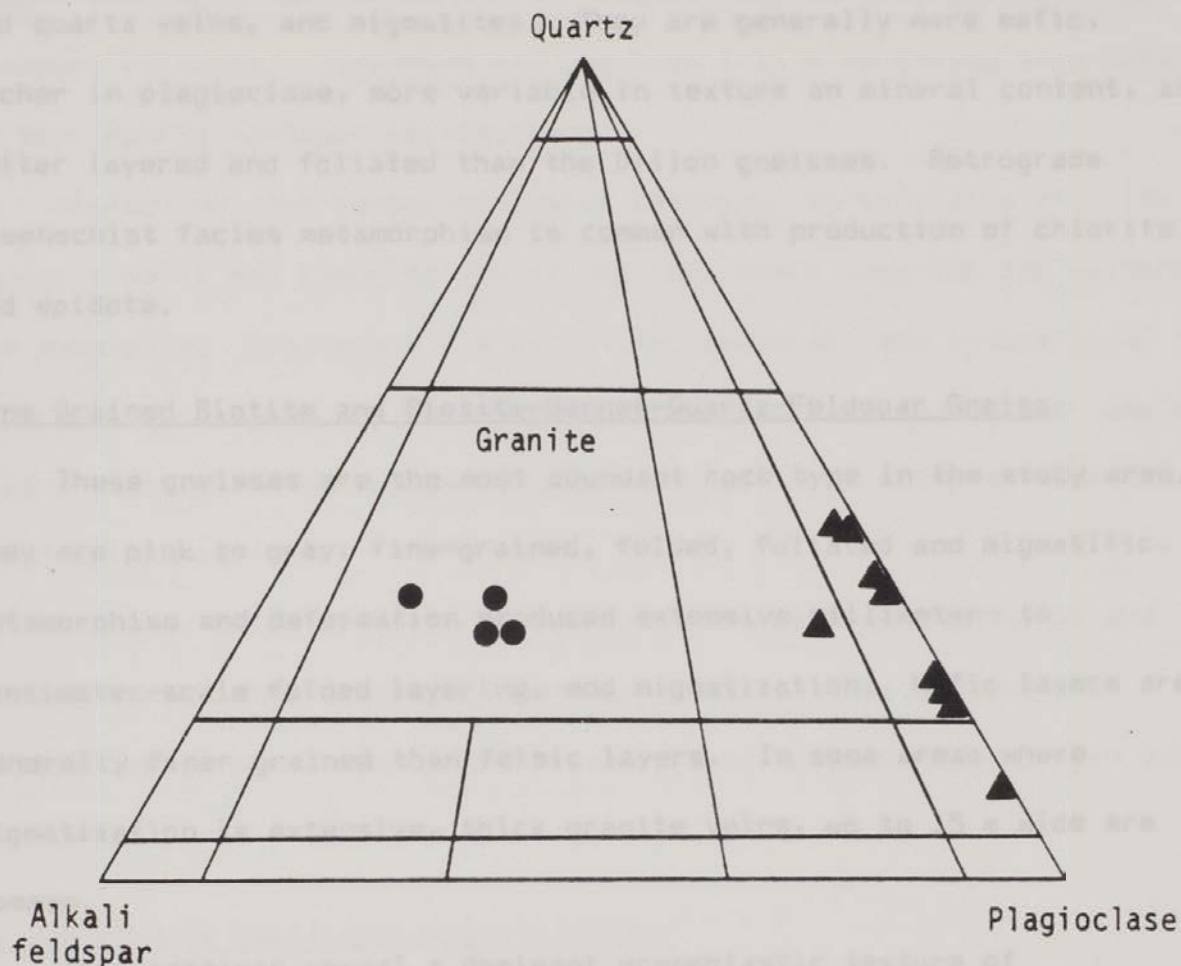


Figure 13. Quartz-plagioclase-alkali feldspar plot of the pre-Cherry Creek Group gneisses (triangles). The circle plots are anatectic pods and veins (coarse biotite gneiss) in these migmatized gneisses.

dominant rock types (figure 3). These rocks contain quartzofeldspathic and quartz veins, and migmatites. They are generally more mafic, richer in plagioclase, more variable in texture and mineral content, and better layered and foliated than the Dillon gneisses. Retrograde greenschist facies metamorphism is common with production of chlorite and epidote.

Fine Grained Biotite and Biotite-Garnet-Quartz-Feldspar Gneiss

These gneisses are the most abundant rock type in the study area. They are pink to gray, fine-grained, folded, foliated and migmatitic. Metamorphism and deformation produced extensive millimeter- to centimeter-scale folded layering, and migmatization. Mafic layers are generally finer grained than felsic layers. In some areas where migmatization is extensive, thick granite veins, up to 15 m wide are common.

Thin sections reveal a dominant granoblastic texture of plagioclase and quartz, with widespread minor amounts of microcline (see table 10). Biotite, including that altered to chlorite, is typically present in amounts greater than 5%, and defines a strong foliation. In one sample traces of sillimanite were found growing from biotite. Alteration minerals include sericite and epidote from plagioclase and chlorite from biotite.

Plagioclase averaging 58% is andesine, An_{31} to An_{34} . Albite twinning is common but untwinned grains dominate. Grains are 0.5 to 2 mm, sub- to anhedral, and generally granoblastic.

Quartz averages 28% and forms 0.2 to 0.5 mm anhedral undulose grains that occur as inclusions in feldspar and as interstitial grain boundary fillings. Stretched and undulose 1 to 2 mm grains also exist in thin quartz-feldspar segregations.

Microcline, the common potassium feldspar, is typically only 1%, except that it may comprise 10% of the rock where layering and veining are extensive. Grains are 0.2 to 0.4 mm, anhedral, and interstitial to plagioclase. In one of the more extensively layered and veined samples (FBG-2) microcline is common in quartzo-feldspathic veins as 1 to 2 mm undulose grains.

Zircons, which exist in all samples, are generally anhedral and rounded to slightly elongate. Hyndman (1985, p. 483) suggest that rounded and irregular zircons are evidence of a sedimentary origin for gneisses.

Coarse Biotite Quartzofeldspathic Gneiss

These gneisses probably originated by partial melting of potassium feldspar-rich fine grained biotite-quartz-plagioclase gneisses or similar gneisses, and may be part of the Dillon gneiss. They occur as centimeter-sized pods with mafic selvages, centimeter- to meter-sized veins with pinch and swell borders and mafic selvages, and most commonly as injection veins up to 15 meters thick intimately associated with fine grained biotite-quartz-plagioclase gneiss. They differ from the fine grained biotite-quartz-plagioclase gneiss in texture as well as composition (see table 10). Unlike the fine grained biotite gneisses, these gneisses are; 1) coarse-grained, 2) unlayered, 3)

homogeneous, 4) fairly massive with biotite only rarely defining a slight foliation, 5) rich in potassium feldspar, and 6) low in mafic minerals, invariably less than 5%. They resemble the massive parts of the Dillon gneiss and vary only texturally from the rest of it. Figure 13 (p. 63), a quartz-plagioclase-potassium feldspar plot of the pre-Cherry Creek gneisses, contains plots of these gneisses. A comparison of these plots with figure 7 (p. 38), a similar plot of the Dillon gneisses, reveals the compositional similarities. These gneisses are pink and have a fairly simple and consistent mineral content.

Potassium feldspar is the most abundant mineral, averaging 49%. Both microcline and orthoclase are present. Gridiron twinned microcline dominates, and string and vein perthite exist in a few samples. The grains are anhedral and range in size from 1 to 7 mm, averaging 4 mm.

Quartz averages 28% as highly undulose 2 to 7 mm grains. In some cases flattened and stretched quartz grains define a foliation. Oligoclase plagioclase, An_{16} to An_{22} , averages 18%. Crystals are 1 to 3 mm, partly sericitized (8 to 20 percent) and only rarely twinned. Rims of unaltered plagioclase are common. Myrmekitic intergrowths of quartz and plagioclase were found in two samples.

Garnet-Sillimanite-Biotite-Quartz-Plagioclase Gneiss

Outcrops of these gneisses are scarce, widely scattered and tend to have very low relief. They are dark gray, well foliated and contain a slight crenulation. Grain size varies from fine to medium on a

centimeter scale. Migmatization produced numerous mafic and felsic segregations. Table 10 gives the modal abundances of the minerals in these gneisses.

Andesine plagioclase An_{30} to An_{34} , is the most abundant mineral, averaging 42%. Grains are anhedral, granoblastic, poikiloblastic, and vary in size from 0.2 to 2 mm. Albite and pericline twinning is common. Some plagioclase grains are flattened, and pods of coarse plagioclase and quartz are common. Graphic intergrowths of plagioclase and quartz exist in the felsic portions of some samples. Alteration to sericite is minor. Quartz averages 40% and resembles plagioclase in occurrence and grain size. Quartz grains are not as poikiloblastic as plagioclase and undulose extinction is strong.

Biotite, sillimanite, and garnet each make up between 3 and 6%. Biotite is pleochroic from yellow to red-brown. Grains are 0.5 to 1.5 mm in length and define a foliation as well as a slight crenulation. Sillimanite occurs as elongate crystals that are 0.1 mm wide and up to 1 mm long. Thin sections cut perpendicular to foliation show sillimanite almost exclusively as diamond-shaped cross sections, which suggests that sillimanite is aligned in a lineation. Sillimanite is colorless to pale gray. It tends to concentrate in 0.5 mm finer-grained layers with biotite, garnet, plagioclase, and quartz, which alternate with quartz and feldspar layers. Pale pink garnet, probably almandine, occurs as slightly flattened poikiloblastic porphyroblasts from 2 to 6 mm in diameter.

Zircon exists as "trains" of anhedral grains, see figure 14. This

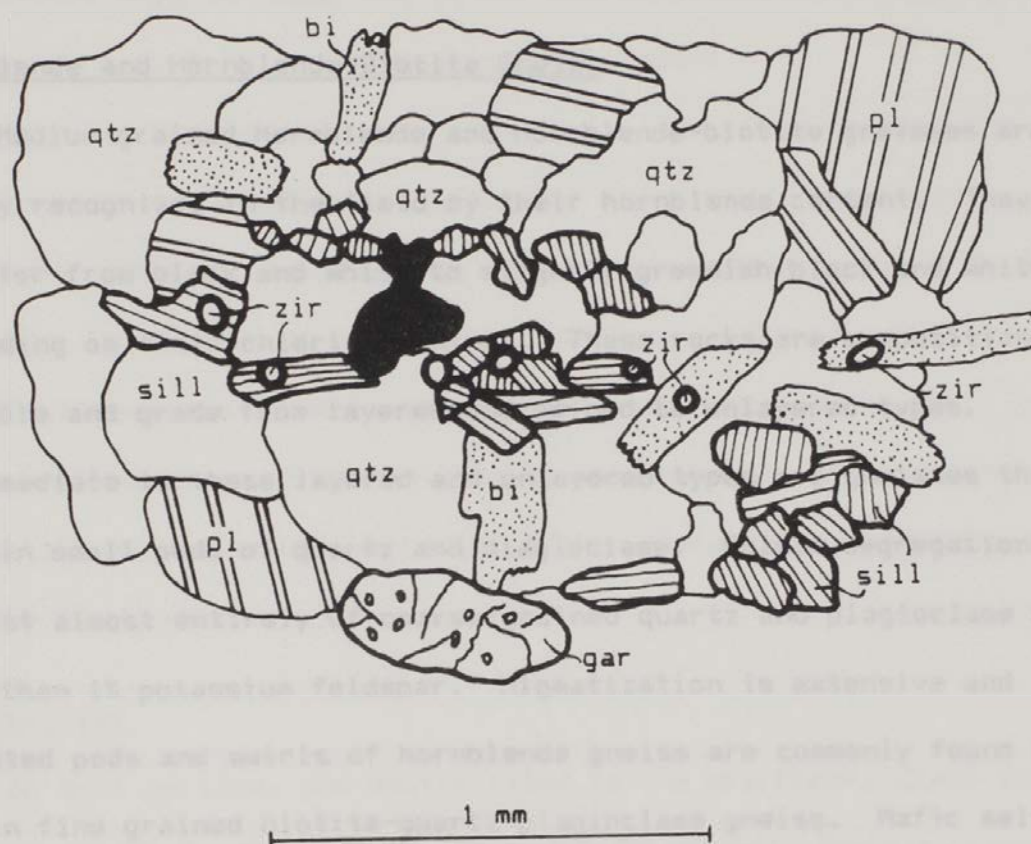


Figure 14. Thin section of garnet-sillimanite-biotite-quartz-plagioclase gneiss of the pre-Cherry Creek Group showing "trains" of rounded zircons. Black is iron oxide, qtz = quartz, pl = plagioclase, bi = biotite, sill = sillimanite, gar = garnet, and zir = zircon.

peculiar occurrence probably represents original sedimentary concentrations of heavy minerals.

Hornblende and Hornblende-Biotite Gneiss

Medium-grained hornblende and hornblende-biotite gneisses are easily recognized in the field by their hornblende content. They range in color from black and white to slightly greenish-black and white, depending on their chlorite content. These rocks are compositionally variable and grade from layered and veined to unlayered types. Intermediate to these layered and unlayered types are gneisses that contain small pods of quartz and plagioclase. Felsic segregations consist almost entirely of coarse-grained quartz and plagioclase with less than 1% potassium feldspar. Migmatization is extensive and isolated pods and swirls of hornblende gneiss are commonly found folded within fine grained biotite-quartz-plagioclase gneiss. Mafic selvages of hornblendite were formed during melting. Veins of quartz as well as plagioclase and quartz are concordant and folded with the host rock.

These hornblende gneisses differ from amphibolites in being lighter colored, coarser grained, richer in quartz, more variable in texture and mineral content, locally containing biotite, and by their extensive migmatization. One 450 meter section in the study area is dominated by fine grained biotite-quartz-plagioclase gneiss and interlayered hornblende gneiss (see figure 3). Table 10 gives the modes for two hornblende gneiss samples and one hornblende-biotite gneiss sample.

Plagioclase and quartz constitute most of all the gneisses.

Potassium feldspar makes up only 1% of one sample. Plagioclase is oligoclase, An_{24} to An_{28} , and is the dominant mineral averaging 47%. Grains are 1 to 5 mm and generally granoblastic.

Hornblende content ranges from 7% to 43%. The samples with less hornblende tend to have more biotite or chlorite. Hornblende is pleochroic from yellow to green, well cleaved and averages 2 to 3 mm. Foliation is slight and only locally defined by hornblende.

Biotite, when present, is generally altered to chlorite. Iron oxide, zircon, tourmaline and calcite are common trace minerals. Alteration minerals include sericite from plagioclase, and chlorite and epidote from biotite.

Amphibolites

In thin section, the amphibolites in the pre-Cherry Creek Group appear similar to those in the Cherry Creek Group. Table 11 gives estimated mineral abundances for these amphibolites.

Unlike the Cherry Creek amphibolites, pre-Cherry Creek amphibolites are not continuous as thick sequences. These amphibolite are widespread as small sills and concordant pods. Cross cutting relations reported by Garihan (1973) indicate that some of these amphibolites originated as dikes, and the folding of these dikes with their host rocks indicates pre- or syn-tectonic emplacement.

Hornblendites are rare and tend to associate with amphibolites. A typical sample consists of 88% hornblende, 8% iron oxide, 3% chlorite, and 1% or less of quartz and zircon. These may represent meta-

ultramafic rock, or some type of metamorphically altered rock.

Table 11. Modal analyses of pre-Cherry Creek Group amphibolites.

Sample # (Am-)	1	2	8	9
Plagioclase	15	43	25	51
Quartz	1	2	1	1
Potassium Feldspar	--	tr	--	--
Diopside	8	3	--	tr
Hypersthene	1	--	--	--
Hornblende	45	50	55	45
Cummingtonite	--	--	1	--
Iron oxide	10	<1	<1	2
Apatite	tr	tr	tr	tr
Calcite	--	--	<1	--
Chlorite	tr	--	--	--
Epidote	1	<1	1	<1
Sericite	20	2	15	1
Hematite	tr	tr	--	--

ultramafic rock, or some type of metasomatically altered rock.

Migmatization

Four major possibilities for the origin of migmatites include; injection of magmas to form granitoid veins or dikes, metasomatism, metamorphic differentiation, and partial melting or anatexis to form granitic pods and veins (Hyndman 1985, p. 471-478).

Migmatites in the pre-Cherry Creek rocks appear to have formed by:

- 1) Injection to form granitoid (coarse biotite quartzofeldspathic gneiss) veins and dikes from 20 cm to 15 m wide, figure 15; evidence supporting this is sharp contacts with the host rock, granitoid composition of the veins that plot near the ternary minimum on a quartz-albite-orthoclase diagram (figure 16) and the lack of mafic selvages to suggest differentiation or melting in place.

- 2) Partial melting and possibly metamorphic differentiation, to form 1 to 5 cm wide pods and veins of quartz and plagioclase within hornblende gneiss and fine grained biotite-quartz-plagioclase gneiss, and granitic material in potassium feldspar rich fine grained biotite-quartz-feldspar gneiss. Characteristics of these include, biotite mafic selvages around the veins and pods, and "pinch-and-swell" borders of the veins (see figure 17).

- 3) Metamorphic differentiation to form millimeter- to centimeter-scale banding of light and dark layers (see figure 17). This is supported by the lack of igneous characteristics for the quartz-feldspar layers. For example, pure quartz layers, and quartz and plagioclase without potassium feldspar are not what would be expected

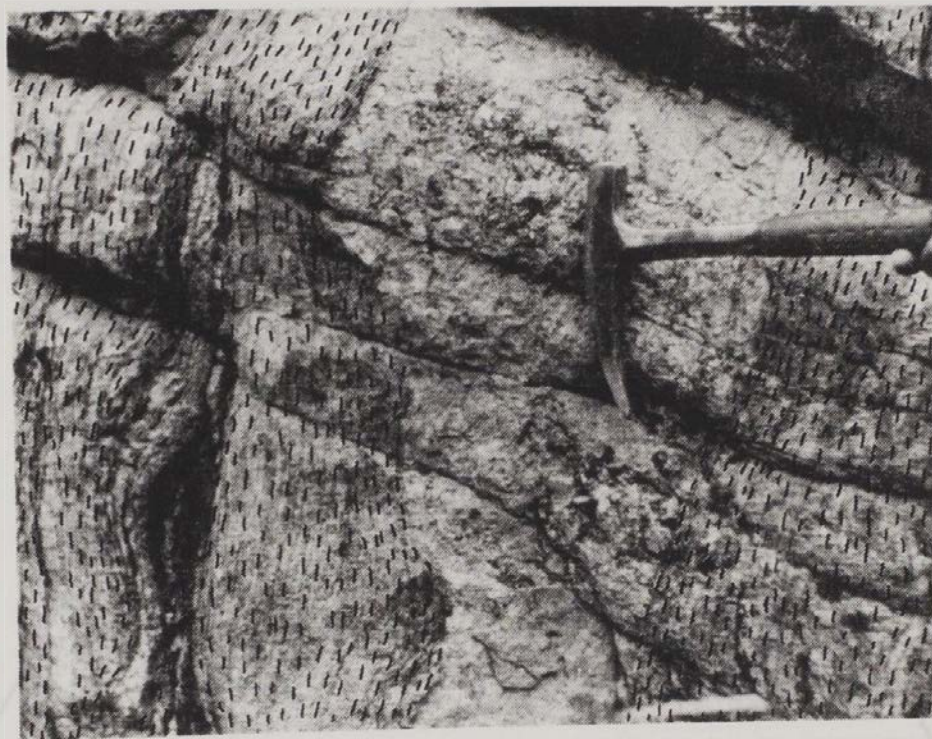


Figure 15. Picture of granitic injection vein in pre-Cherry Creek Group fine grained biotite-quartz-plagioclase gneisses. the estimated primary mineral of this system for an aegirine content of 25 and pressures of 5 to 7 kbars. Taken and modified from Luth (1976).

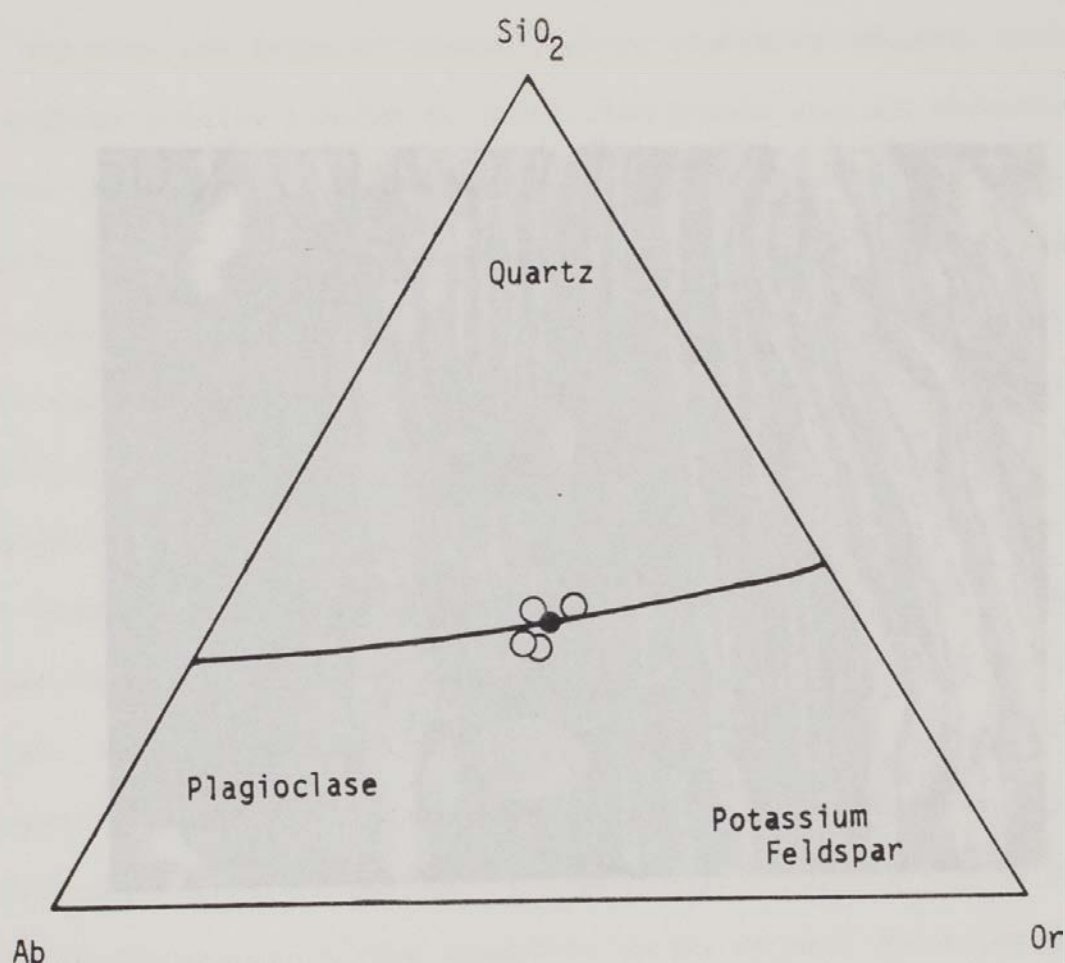


Figure 16. Quartz-albite-orthoclase plot of anatectic pods and veins of the pre-Cherry Creek gneisses. The solid circle is the estimated ternary minimum of this system for an anorthite content of 25 and pressures of 5 to 7 kbars. Taken and modified from Luth (1976).



Figure 17. Picture of pre-Cherry Creek Group migmatite. Thin continuous layers in this biotite rich migmatite are probably related to metamorphic differentiation. The thicker "pinch and swell" bordered veins with mafic selvages may be anatectic in origin.

from melting.

The pods and veins of coarse biotite-quartzofeldspathic gneisses are compositionally similar to the Dillon gneiss and are probably related to it in one or more ways. The injection veins could be either 1) material intruded into the pre-Cherry Creek rocks from the intrusion of the Dillon gneiss or, 2) veins melted out of the pre-Cherry Creek rocks and intruded only a short distance through these rocks. The small pods and veins of granitoid composition that apparently formed through partial melting of the pre-Cherry Creek gneisses clearly show that these rocks experienced some melting and that some of the melt formed had a composition similar to the injection veins and the Dillon gneiss. Gradations from slight anatexis of the gneiss where mafic selvages exist to injection veins of the same composition suggest that partial melting of the pre-Cherry Creek rocks or similar rocks below could be the source for the injection veins, as well as of the Dillon gneiss.

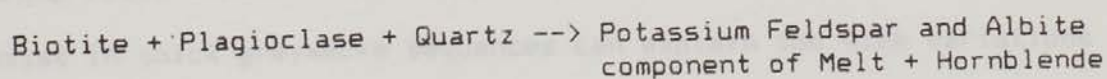
ORIGIN OF THE PRE-CHERRY CREEK GROUP

Detailed information on the pre-Cherry Creek unit is sparse. Garihan and Williams (1976) considered a sedimentary origin for the gneisses most likely. They believed this primarily because; 1) the garnet-sillimanite-biotite rocks have a composition that strongly suggests a shaley protolith, 2) the wide variation in feldspar and quartz contents in garnet-biotite gneiss, and 3) because all the gneisses are concordant, randomly interlayered, and locally show

gradational contacts.

Rounded zircons common in the fine grained biotite-quartz-plagioclase gneiss also support a sedimentary origin for this rock type. Layers of zircon in the garnet-sillimanite-biotite-quartz-plagioclase gneiss (figure 14) probably represent original sedimentary layering, where the zircons concentrated as heavy minerals. This as well as the composition, provide strong evidence for a sedimentary protolith for the garnet-sillimanite-biotite-quartz-plagioclase gneisses.

Hornblende gneisses and hornblende-biotite gneisses could have protoliths of tonalite or mafic rich greywacke. One striking feature of these rocks is their intense migmatization. The rock association in the hornblende gneiss zone on figure 3 consists of fine grained biotite-quartz-feldspar gneiss, hornblende-biotite gneiss, and hornblende gneiss with associated quartz and plagioclase veins and pods. Winkler (1976, p. 311) showed that during migmatization hornblende is formed by the reaction:



Estimated compositions calculated from the mineral percentages, and field relations, support a possible residual-melt relationship for the hornblende gneisses and the commonly associated quartz, minor potassium feldspar, and plagioclase rocks. Chemical compositions also suggest possible original rock types such as the fine grained biotite-

quartz-plagioclase gneiss or hornblende-biotite gneiss. Thus, the reaction:

Biotite or Hornblende-Biotite Gneiss \rightarrow Hornblende Gneiss + Melt

may have operated during migmatization. It is possible that all the different rock types in this migmatized zone represent segregation of a more homogeneous original rock type through partial melting or metamorphic differentiation. If so, then a good portion of the hornblende gneisses in these rocks could be residual material from partial melting that occurred during migmatization to form felsic material. The abundance of hornblende mafic selvages in the gneisses supports, but does not prove this hypothesis. In the present state of knowledge, this idea is only speculative. A sedimentary origin for the hornblende gneisses appears most probable from their interlayering with fine grained biotite-quartz-plagioclase gneiss, which I believe to be of sedimentary origin.

A greywacke protolith for the gneisses of the pre-Cherry Creek Group would explain their composition. Compositional variations that exist in thick greywacke sequences can explain the wide variations in rock types and mineral percentages found in these gneisses. Thin mud layers common in modern greywacke sequences (Blatt et al, 1980, p. 373-375) may be represented here by garnet-sillimanite-biotite gneisses and chlorite schists found and described by Garihan (1973), and biotite schist (Heinrich, 1960). Available evidence suggests a sedimentary origin for the majority of the gneisses present in the pre-Cherry Creek

unit, and I expect further data to support a dominantly sedimentary origin for these gneisses.

The composition of the coarse biotite-quartzofeldspathic gneisses is within the range of melt compositions produced by experimental anatexis of biotite-quartz-plagioclase rocks similar to the fine grained biotite-quartz-plagioclase gneisses (Winkler 1976, p. 308-323). This, as well as field evidence mentioned in the migmatite section above, supports an igneous origin for these gneisses and also indicates a possible origin by partial melting of some of the pre-Cherry Creek gneiss or similar gneisses below.

The cross cutting relations of some amphibolites (Garihan, 1973) indicate an origin as dikes and the field relations of these suggest pre- or syntectonic emplacement. Concordant amphibolites may be basalt flows within the pre-Cherry Creek sediments.

Outcrops are dark brown to green and vary high in the topography. Large 1 to 5 cm brown-brown orthopyroxene crystals set in a fine-grained groundmass of dark amphibole give a bumpy appearance to these rocks, Figure 19. These large orthopyroxene crystals are commonly present, but where absent, the rock tends to be smooth using the abundant elongate amphibole crystals.

Table 12 gives the mineral modes for a few of these samples. These rocks commonly contain large orthopyroxene crystals set in a fine-grained recrystallized groundmass of albite and amphibole, Figure

META-ULTRAMAFIC ROCKS

Ultramafic rocks exist in all three major units of the Ruby Range. They are volumetrically minor but widespread, most commonly as small pods, meters to tens of meters wide, elongate parallel to foliation. However, one large 2 km body, the Wolf Creek body, exists in the southern part of the range (Heinrich, 1960). A detailed description of these rocks is given by Desmarais (1978).

In the Cherry Creek Group, pods of ultramafic rock are common in amphibolite and pelitic sequences. In the Dillon gneiss they are associated with layers and pods of amphibolite, commonly in the crests of small isoclinal folds. Although they were not found in the Cottonwood Creek study area, maps by others (Heinrich, 1960; Garihan, 1973) show them within the pre-Cherry Creek Group. In fact, the Wolf Creek body is within this group.

Outcrops are dark brown to green and form highs in the topography. Large 1 to 5 cm bronze-brown orthopyroxene crystals set in a fine-grained groundmass of dark amphibole give a knobby appearance to these rocks, figure 18. These large orthopyroxene crystals are commonly present, but where absent, the rock tends to be schistose owing the abundant elongate amphibole crystals.

Table 12 gives the mineral modes for a few of these samples. These rocks commonly contain large orthopyroxene crystals set in a fine-grained recrystallized groundmass of olivine and amphibole, figure

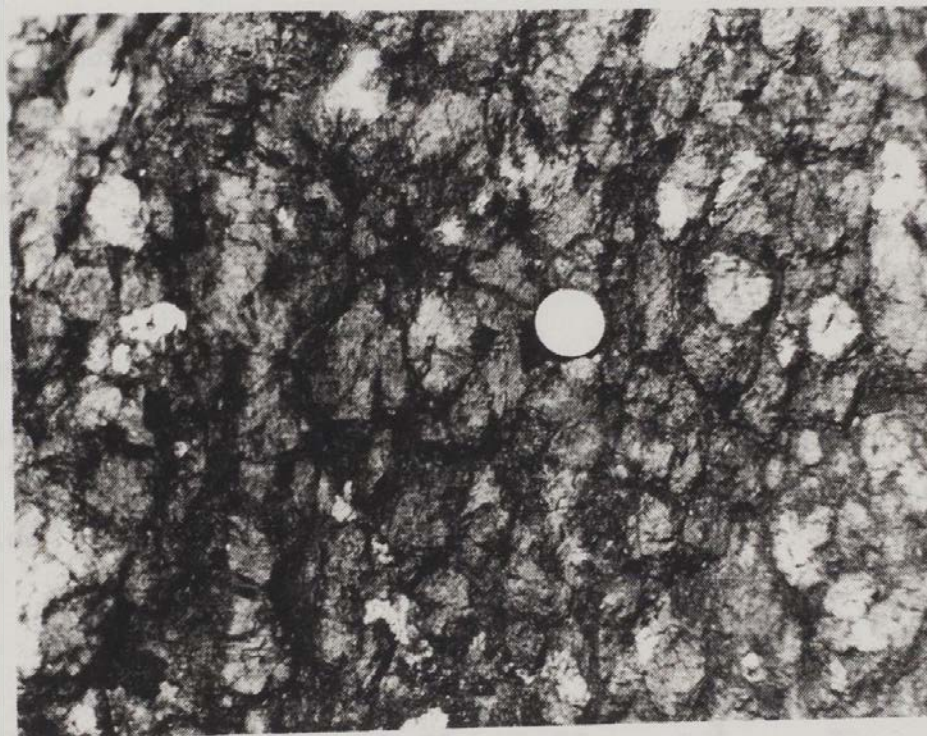


Figure 18. Picture of meta-ultramafic rock showing large hypersthene crystals set in a finer grained matrix of amphibole. Note the dime for scale.

18. Iron oxide and spinel are common accessory minerals. Alterations include; serpentine from olivine, and talc from anthophyllite and hypersthene.

Table 12. Modal analyses of meta-ultramafic rocks

Hypersthene	10	20	70	56	55	--
Olivine	5	--	5	13	5	--
Cummingtonite/ Anthophyllite	--	30	--	--	2	2
Actinolite/ Tremolite	80	47	20	25	30	97
Iron oxide	3	3	5	3	5	--
Spinel	2	--	--	--	tr	--
Talc	--	--	--	--	2	1
Serpentine	tr	--	--	3	--	--

Hypersthene is commonly the most abundant mineral in these rocks. It occurs as large crystals up to 2 cm across that contain inclusions of all the other minerals. In samples containing abundant amphibole and lesser hypersthene, only patches of large optically continuous crystals remain. These patches and crystals are colorless to pale pink and commonly contain strain features such as fractures, kink bands, and undulose extinction. Olivine occurs as 2 mm colorless fractured grains that locally form outlines of larger grains, up to 6 mm. Serpentine and iron oxide are common along fractures as alteration products.

Amphiboles are cummingtonite/anthophyllite and actinolite/tremolite. Pale green actinolite is the most common. It occurs as 0.5 to 1.5 mm crystals, commonly elongate. In some samples actinolite surrounds hypersthene crystals, suggesting some type of reaction relationship. Desmarais (1978) suggested that many of these ultramafic rocks were serpentinized prior to metamorphism and recrystallization, and possibly emplaced as serpentinites. If so, the actinolite may represent recrystallization of serpentine that originally formed from and surrounded olivine and/or hypersthene. Anthophyllite is common as colorless blades up to 5 mm long.

Iron oxide exists as irregularly shaped grains in every sample. It occurs with serpentine in fractures in olivine, as random grains throughout the rock, and as trains of grains in feathery patterns within actinolite (see figure 19). Desmarais also noted these feathery patterns and interpreted them as iron oxide trains formed by earlier serpentinization. It appears that original olivine was serpentinized, forming iron oxide as a by-product. Then this was metamorphosed during amphibolite-facies metamorphism causing recrystallization of the serpentine to actinolite, leaving iron oxides as trains in actinolite. The patterns formed by these iron oxide crystals resemble those formed by serpentinization and appear to be more than just a random occurrence. This is supported by the presence of recrystallized actinolite around these iron oxides. Progressive de-watering of these serpentinized ultramafic pods would also explain the metasomatism associated with these pods to form anthophyllite/actinolite schists in

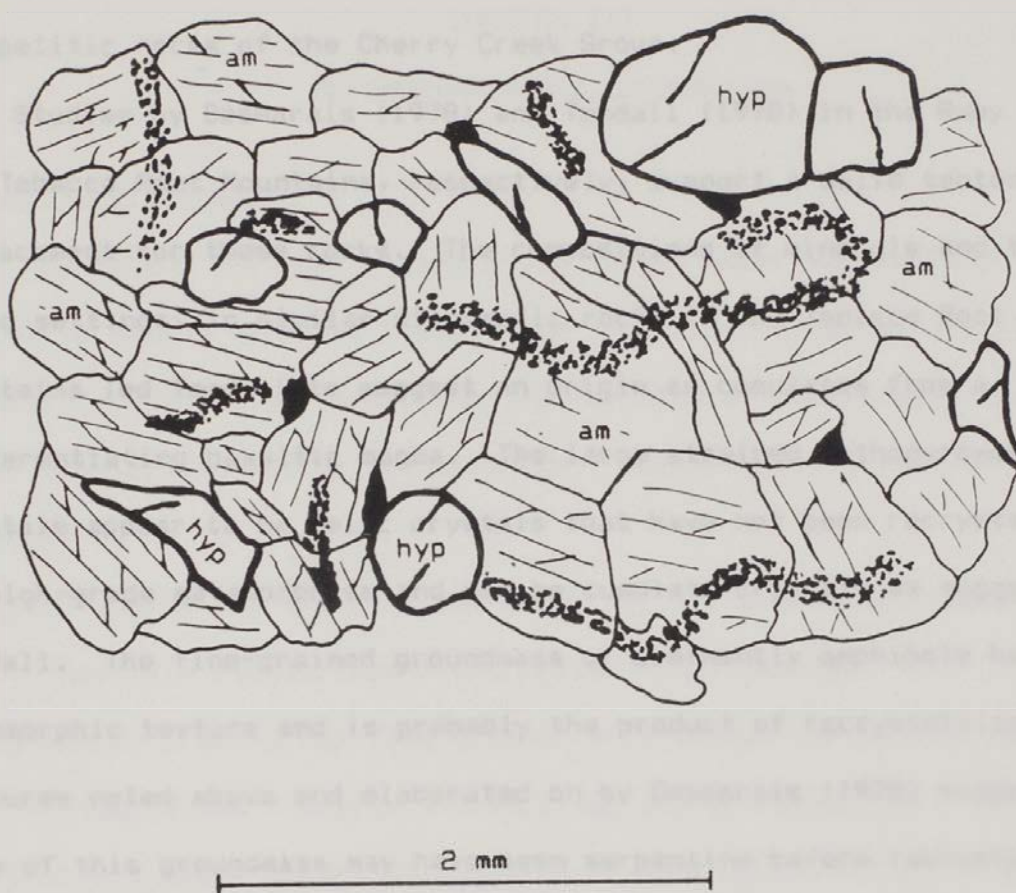


Figure 19. Thin section of meta-ultramafic rock showing feathery patterns of iron oxide in amphibole. Patterns are believed to have formed by serpentinization which occurred before metamorphism and recrystallization to amphibole. Black is iron oxide, am = actinolite, and hyp = hypersthene.

the pelitic rocks of the Cherry Creek Group.

Studies by Desmarais (1978) and Tendall (1978) in the Ruby Range and Tobacco Root Mountains, respectively, support a solid tectonic emplacement for these rocks. The compositions of minerals and their field settings, in similar ultramafic rocks in the Tobacco Root Mountains led Tendall to suggest an origin as cumulates from a differentiating basaltic magma. The large strained orthopyroxene crystals appear to be relic crystals that have not been recrystallized by high-grade metamorphism and may be cumulate crystals as suggested by Tendall. The fine-grained groundmass of dominantly amphibole has a metamorphic texture and is probably the product of recrystallization. Textures noted above and elaborated on by Desmarais (1978) suggest that some of this groundmass may have been serpentine before recrystallized to amphibole. Thus, these ultramafic bodies may have originally been serpentized and partially serpentized peridotites, possibly of oceanic crust of upper mantle origin. The location of these bodies in the crests of small isoclinal folds, possibly due to their migration into areas of low stress, and the presence of material that was apparently recrystallized during high-grade metamorphism suggests tectonic emplacement of these ultramafic pods occurred before or during high-grade metamorphism and deformation.

CHAPTER III

METAMORPHISM AND DEFORMATION

Prograde Metamorphism

High-grade regional metamorphism in the upper amphibolite to lower granulite facies affected Precambrian rocks throughout southwestern Montana. In the study area, equilibrium mineral assemblages indicate upper amphibolite facies metamorphism. Assemblages indicative of this include:

Dillon gneiss and Cherry Creek Group pelitic schist and gneisses;

Quartz + Plagioclase + Orthoclase + Sillimanite

Pre-Cherry Creek Group fine grained biotite-quartz-feldspar gneisses;

Plagioclase + Quartz + Orthoclase and/or Microcline + Biotite

Pre-Cherry Creek garnet-sillimanite-biotite-quartz-feldspar gneisses;

Plagioclase + Quartz + Biotite + Garnet \pm Sillimanite

Pre-Cherry Creek and Cherry Creek Group amphibolites;

Hornblende + Plagioclase \pm Diopside \pm Garnet

Cherry Creek Group marble;

Carbonate + Diopside \pm Biotite

Cherry Creek Group calc-silicate gneisses;

Carbonate + Tremolite + Epidote + Garnet + Plagioclase

Cherry Creek Group iron-formation;

Quartz + Hypersthene + Anthophyllite + Grunerite + Augite

The presence of orthoclase and sillimanite without muscovite

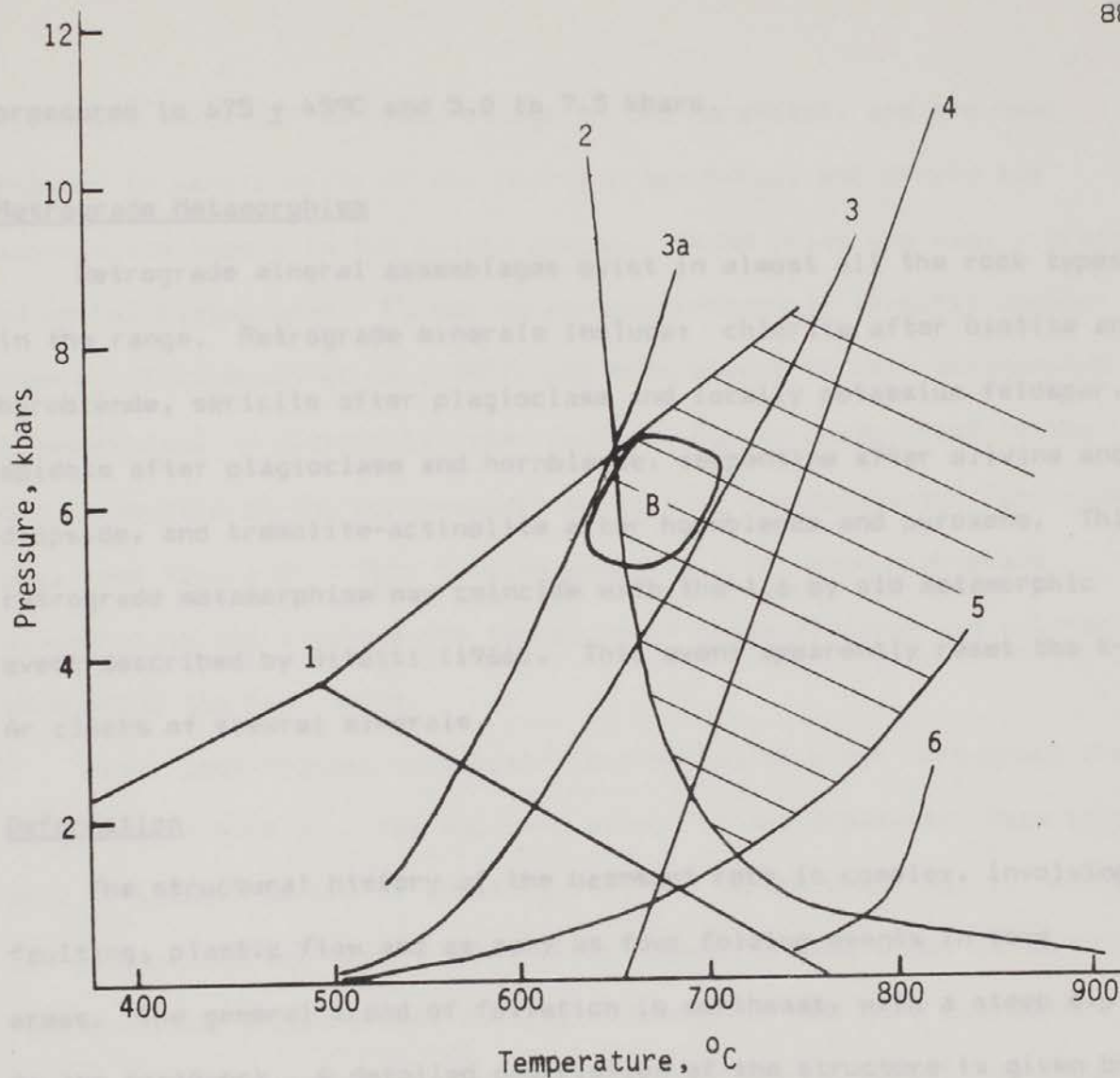
indicates metamorphism reached the sillimanite-orthoclase zone. Amphibolites in the Dillon gneiss have the granulite facies mineral assemblage;

Plagioclase + Hypersthene + Diopside + Hornblende \pm Garnet

This assemblage may be the result of metamorphism in a relatively dry environment, rather than under true granulite facies temperatures and pressures, which would be higher than those indicated by the surrounding rocks. However, this assemblage does indicate temperature and pressures were near granulite facies.

Other characteristics of this area that indicate upper amphibolite to granulite grades of metamorphism include: 1) The presence of migmatite and granitic veins which is especially common in the sillimanite orthoclase zone, 2) The abundance of red-brown biotite and dark olive green to brown hornblende, 3) Plagioclase content is greater than An₂₅ (Winkler, 1976), 4) The presence of perthite and antiperthite indicates granulite facies, and 5) strung out quartz crystals like those in the Dillon gneiss (figure 8, p. 40) are common in granulite grade rocks.

A pressure-temperature diagram, figure 20, gives constraints on the conditions of metamorphism for this area. The temperature is constrained to 650 to 850°C. The pressure is less constrained and is in the range of 2 to 12 kbars. Area B on this figure is the range of pressures and temperatures determined by Dahl (1976) for the Sweetwater Pass study area. Major element geothermometers and grade indicators of various minerals allowed him to better constrain the temperatures and



1. Kyanite --> Andalusite --> Sillimanite
2. Common granite melting curve
3. Muscovite + Quartz --> Sillimanite + Orthoclase ($PH_2O=1$)
- 3a. Muscovite + Quartz --> Sillimanite + Orthoclase ($PH_2O=0.5$)
4. Potassium feldspar --> Perthite or Antiperthite
5. Calcite + Quartz --> Wollastonite + Carbon Dioxide ($X_{CO_2}=1$)
6. Amphibole + Plagioclase + Clinopyroxene + Ilmenite --> Amphibole + Plagioclase + Clinopyroxene + Orthopyroxene + Ilmenite

Figure 20. Pressure-temperature diagram showing field of metamorphism (Hyndman, 1985, p. 516-527). Field B is for the Sweetwater Pass study area, taken from Dahl (1976).

pressures to $675 \pm 45^\circ\text{C}$ and 5.0 to 7.5 kbars.

Retrograde Metamorphism

Retrograde mineral assemblages exist in almost all the rock types in the range. Retrograde minerals include: chlorite after biotite and hornblende, sericite after plagioclase and locally potassium feldspar, epidote after plagioclase and hornblende, serpentine after olivine and diopside, and tremolite-actinolite after hornblende and pyroxene. This retrograde metamorphism may coincide with the 1.6 by old metamorphic event described by Giletti (1966). This event apparently reset the K-Ar clocks of several minerals.

Deformation

The structural history of the basement rock is complex, involving faulting, plastic flow and as many as four folding events in some areas. The general trend of foliation is northeast, with a steep dip to the northwest. A detailed description of the structure is given by Karasevich et al (1981).

Three sets of folds were noted in the study areas. F_1 folds are tight isoclinal folds that display axial plane schistosity parallel to bedding, striking northeast and dipping to the northwest. Folding accompanied metamorphism. Mechanisms of folding include passive and flexural flow (Okuma, 1971). F_1 folds are best exposed as hand sample- to outcrop-size folds in banded gneisses and pelitic rocks, and slightly larger less obvious folds in sequences of interlayered Dillon gneiss, amphibolite, meta-ultramafic and pelitic gneiss. Large F_2

folds are isoclinal to open, plunge to the northeast, and are best exposed in marble units of the Cherry Creek Group, and marble and amphibolite layers in the Dillon gneiss. These folds are easily traced on aerial photographs. F_2 may be contemporaneous or slightly younger than F_1 (Karasevich et al (1981)), but both appear to have accompanied metamorphism. A distinctly later folding, F_3 , is exemplified in the Dillon Synform in the northwestern portion of the Sweetwater Pass study area (see figure 2). This folding event is later than high-grade metamorphism and involves the formation of large synforms and antiforms throughout the Ruby Range.

Major post-Archean northwest-trending faults exist throughout the Range (see figure 1). The southern extent of the Sweetwater Pass study area is bounded by one of these faults, the Carter Creek Fault. Almost all contacts of the Cherry Creek Group appear to have acted as ductile faults during metamorphism, causing boudinage of the more competent units. Evidence for late movement (possibly related to uplift) along these contacts is seen by minor offset, at these contacts, of the cross cutting 1.1 to 1.5 b.y. old diabase dikes.

CHAPTER IV

GEOLOGIC HISTORY AND TECTONIC INTERPRETATION

Geologic History

The Precambrian geologic history of the Ruby Range determined from protolith interpretations, field relations and radiometric-age data is summarized in table 13.

Table 13. Precambrian geological history of the Ruby Range

Age (m.y.)	Events
1,120	Diabase dike emplacement (Wooden et al, 1978)
1,455	Diabase dike emplacement (Wooden et al, 1978)
1,600	Regional thermal event; not a rock forming event, however, pegmatite emplacement may have occurred (Giletti, 1966).
2,750	Deformation, upper amphibolite grade regional metamorphism, and emplacement of the Dillon gneiss (James and Hedge, 1980).
>2,750	Deposition of the sediments and volcanics of the pre-Cherry Creek Group, and stable shelf sedimentation and volcanism of the Cherry Creek Group.

The pre-Cherry Creek Group rocks have a greywacke protolith, with subordinate pelitic layers of shale parentage. Amphibolites of basaltic origin, dikes, sills and possibly flows, are common. Thick greywacke sequences with interlayered basalt are generally of deep

basinal or ocean floor origin.

The Cherry Creek Group contains a shallow water shelf to slope sequence of quartzite, carbonate, and shale. Appreciable amounts of amphibolite in this group suggest deposition occurred during a rifting event.

The relationship of the Cherry Creek Group to the pre-Cherry Creek Group is poorly understood because injection of the Dillon gneiss between these two units has obscured direct observation of their contact. The Cherry Creek Group structurally overlies the pre-Cherry Creek Group in the Ruby Range. Cross sections through the least deformed portion of the Ruby Range show no indication of major overturning of this sequence (Karasevich et al, 1981). Vitaliano et al (1979) suggested that if the rocks in the Ruby and Tobacco Root Ranges are both right side up, younger to the east, then the gneisses of the Tobacco Root Mountains may correlate with those of the pre-Cherry Creek Group. If so, then a better exposed relationship between the Cherry Creek Group and pre-Cherry Creek Group may exist in the Tobacco Root Mountains, where the Dillon gneiss may be less widespread, or absent.

Assuming the basement rock is not overturned, possible relationships between the Cherry Creek Group and pre-Cherry Creek Group include: 1) these two rock units may be depositionally related; either different phases of a depositional cycle or different facies of a single depositional environment, 2) the pre-Cherry Creek Group may have been an early formed basement on which the Cherry Creek Group was

deposited, or 3) they could represent fault slices from unrelated environments.

Typical continental margin sedimentary sequences, as outlined by Dickinson (1974), include an early basinal clastic phase that might be similar to the pre-Cherry Creek Group, then a carbonate-shale phase similar to the Cherry Creek Group. Toward the ocean, this shelf/slope wedge grades into deep water turbidite deposits and volcanic rocks similar to the pre-Cherry Creek Group (idealized model of Dickinson, 1974; and Cordilleran miogeocline Stewart and Poole, 1974).

Wilson (1972) showed that the interface between basement and cover controlled the injection of granitic rock in the Rhodesian Archean Craton to create concordant sheet intrusions. The concordant injection of the Dillon gneiss between the Cherry Creek and pre-Cherry Creek groups similarly suggests a zone of weakness, thus, making a fault or basement-cover relationship more probable. The lack of any common rock types within these units also favors this relationship. Gilletti (1966) gives a whole rock Rb-Sr date of 3.1 b.y. for the pre-Cherry Creek gneisses in the Blacktail Range, south of the Ruby Range. This date is significantly older than the 2.75 b.y. dates given for the amphibolite grade metamorphism in the Ruby Range (James and Hedge, 1980), and may support the idea of the pre-Cherry Creek Group being an early formed basement. Work by Erslev (1983) on what may be correlative rock packages in the Madison Range shows the Cherry Creek and pre-Cherry Creek groups to be two depositionally unrelated sequences.

In contrast to the ideas presented above, if the Dillon gneiss is

dominantly sedimentary in origin, then all the rocks in the Ruby Range, including the Dillon gneiss, may represent one continuous sequence of deposition.

The Cherry Creek Group is particularly important in that it records a period of tectonically stable shelf to slope deposition older than 2.75 b.y.. Supracrustal sequences like the Cherry Creek Group are common in Archean high-grade terrains (see references in Windley, 1984, p. 8-27), and are distinctly different from the greywacke-turbidite association in low-grade greenstone belts (Windley, 1984). Although common, these supracrustal sequences are volumetrically minor. They appear to record short periods of tectonic stability in the generally active tectonic regime of the Archean.

Deformation, metamorphism, migmatization of the pre-Cherry Creek Group, and concordant intrusion of the Dillon gneiss occurred 2.75 b.y. ago. Compositional similarities between anatectic veins and pods of the pre-Cherry Creek Group migmatite and the Dillon gneiss suggest the Dillon gneiss may have originated by partial melting of the pre-Cherry Creek gneisses or similar gneisses underlying them. The high potassium content of the Dillon gneiss also favors an origin by crustal melting. The lack of dominant migmatite in the Dillon gneiss suggests the intrusion moved from its source, but the concordant contacts suggest that it did not travel far. The presence of foliation, and the dominance of fairly homogeneous plutonic rock that grades laterally into migmatized country rock likewise suggest proximity to the melting environment (Hutchison, 1982). Emplacement may have been partly

controlled by the Cherry Creek Group/pre-Cherry Creek Group contact. During intrusion, inclusions and layers of amphibolite, minor pelitic gneiss, and marble, which originated as part of the Cherry Creek Group, may have been incorporated within and between sheets of intrusive granite. Deformation and folding occurred after injection, forming mylonitic textures. Recrystallization of this mylonitic fabric suggests metamorphism outlasted deformation.

If sedimentary in origin, the Dillon gneiss deposition is gradational from and into pre-Cherry Creek Group and Cherry Creek Group sedimentation, and may represent early rift generated sands from a nearby continental source, possibly a granitic terrain.

Meta-ultramafic pods exist in all the units of the Ruby Range. Possible origins include intrusions or fragments of intrusions, and fragments of oceanic crust or upper mantle. The small size of the meta-ultramafic rock bodies in the Ruby Range is hard to rationalize with an intrusive origin. Field relations favor tectonic emplacement rather than an intrusive origin (Desmarais, 1978; Tendall, 1978), and textures noted by Desmarais (1978) indicate that some of these meta-ultramafic rocks were serpentized before metamorphism, and later recrystallized. Thus, the most probable origin for these rocks is as pods of oceanic crust or upper mantle emplaced along faults as serpentized and partially serpentized peridotites. Emplacement of these pods occurred before or during metamorphism and deformation, as indicated by the recrystallization of these rocks, and their participation in folding.

Tectonic Interpretation

Before a model for the origin of an Archean rock package such as that of the Ruby Range can be constructed, the question "did plate tectonics operate in the Archean" should be considered. Windley (1984, p. 48-65) reviews the recent knowledge and beliefs concerning crustal evolution in the Archean. Several processes and models have been proposed to explain continental growth in the Archean, however, most authors now favor the operation of some form of plate tectonic processes, "proto-tectonics", for the Archean. Windley gives the details of why proto-plate tectonic models are favored over the others and states his belief that proto-tectonic processes are the only process known that will satisfactorily explain the origin of the world's Archean terrains.

Release of more radioactive heat during Archean time must have caused several differences in plate tectonic processes. Hargraves (1978) suggested that geothermal gradients beneath Archean continental crust was much greater than at present. However, this idea is not necessarily valid as pointed out by several workers and reviewed by Windley (1984, p.341-343). Other workers believe that the largest part of the heat loss in the Archean was through convection rather than conduction and that this heat was removed through rapid production of oceanic crust and faster sea floor spreading. Thus, significantly higher crustal temperatures and geothermal gradients may not be characteristic of the Archean.

If heat loss was through convection, a high rate of plate movement

and continental growth would have existed (Bickle 1978, Burke and Kidd 1978). Sleep and Windley (1982) argue that the oceanic crust must have been greater than 20 km thick and that this crust tended to resist subduction, but could not prevent it. Windley and Smith (1976) suggest that shallow subduction of young hot buoyant crust occurred in the Archean. With shallow subduction, arc magmatism might be expected to occur in wider belts than those found in later times. Windley (1984) suggests that continental growth was widespread because the plates were small whereas in later times growth was limited to continental margins of larger plates. Thus, the generally active tectonic regime of the Archean, which many believe to have formed up to 80% of the present continental crust, probably involved rapid subduction, rifting, and numerous collisions.

If the above differences and their implications on tectonics in the Archean are considered, then comparisons to modern tectonic environments provide an excellent tool for understating Archean geological environments.

The total rock package of the Ruby Range resembles many Archean high-grade terrains. Quartzofeldspathic gneiss, the bulk of which is believed to be metamorphosed and deformed plutonic rock (Windley, 1984, p. 9-11), is the dominant rock type in most Archean high-grade terrains. These gneisses contain inclusions of various other rocks, all of which are similar to rocks of the Cherry Creek Group. The sequences of events proposed for the Ruby Range is common for Archean high-grade terrains including those in, Labrador, Greenland

(Bridgewater et al, 1978), and the Limpopo Belt of South Africa (Barton and Key, 1981; Robertson and du Toit, 1981).

First, is the deposition of a supracrustal sequence of volcanic amphibolites, pelitic sediments, quartzites, carbonates, and iron-formation. Then, intrusion of massive quantities of granitic rock, mostly tonalitic in composition, occurred with deformation, and amphibolite- to granulite-facies metamorphism. After this, deposition of more supracrustal rocks occurred. These rocks, along with the earlier metamorphosed supracrustal rocks and plutonic gneisses, were later subjected to high-grade metamorphism, tectonic intercalation, and injection of plutonic rock of granitic composition. In all cases injection of potassium rich granitoids is late in the Archean history of these terrains. The history of the Ruby Range appears to be very similar to this latest event. The similarity of events for various regions suggests common tectonic process operated to form these terrains.

In a plate tectonic model for crustal growth in the Archean, Windley (1984) suggests that the early plutonic events, in which injection of tonalite occurred, were related to proto-Andean type arc magmatic activity on mini-continental plates of the Archean. The second stage of Archean crustal growth in this model involves the aggregation of these mini-continental plates to gave rise to extensive continental plates in late Archean time. This second event, which provides a model to explain the history of the Ruby Range involved high-grade metamorphism, deformation, tectonic intercalation, and

injection of late potassium-rich granite.

Fountain and Desmarais (1980) proposed an accretionary prism environment for the origin of sedimentary rocks of the Montana basement including the Ruby Range. They propose a fore-arc basin depositional environment for the Cherry Creek Group. They believe deposition occurred either in a large fore-arc basin above a trench, or in small basins developed between fault blocks of the accretionary prism. Wilson (1981) supports this suggestion for sequences in the Ruby and Tobacco Root Mountains. Turbidites generally accumulate in these basins, however, Fountain and Desmarais (1980) and Wilson (1981) suggest that appropriate environmental conditions could favor deposition of other sediment types, possibly limestone or iron-formation. They also mention that carbonate rocks are accumulating in modern fore-arc basins (Karig, 1970). Carbonates do exist in these assemblages, but they are very minor, commonly making up the least abundant rock type.

The great abundance of carbonates in the Cherry Creek Group, as well as the overall rock association of quartzite-carbonate-shale is very difficult to explain using a fore-arc basin depositional environment. Carbonate deposition usually occurs during tectonically stable conditions when detrital sediment supply is low; a fore-arc basin environment does not generally provide these conditions. If plate movement and subduction were increased in the Archean, as suggested above, then achieving tectonic stability and low sediment supply in an accretionary prism or fore-arc environment would be more

unlikely than it is today. Thus, different environmental conditions in Archean time may favor less carbonate in this environment rather than more, as suggested by Fountain and Desmarais, and Wilson. It is possible that the sediments and volcanics of the Cherry Creek Group existed as blocks within an accretionary prism environment, however, it is highly unlikely they accumulated in this environment.

Metamorphism in an accretionary prism environment is dominantly low temperature. Wilson (1981) suggests that higher thermal gradients in the Archean could have resulted in the upper amphibolite to granulite grades of the Ruby Range, however, as mentioned above, the geothermal gradients may not have been significantly higher in the Archean.

Hanley (1975) proposed a back-arc or marginal basin (Tarney et al, 1976) depositional environment for similar rocks of the Tobacco Root Mountains. This depositional environment works well for many of the Archean greenstone belts (Windley, 1984), however, fails to account for the quartzite-carbonate-shale sequence of the Cherry Creek Group which is distinctly different from greywacke-shale sedimentary sequences of greenstone belts. Wilson (1981) points out other problems with this depositional environment, these include;

- 1) Sedimentation and deformation in back-arc basins is commonly diverse across small distances. However, the Montana basement is characterized by lithologic and structural continuity over great distances.
- 2) Back-arc basins commonly contain significant portions of

ophiolite sequences. They are not present in the Montana basement.

It is possible that the Cherry Creek Group was deposited in a well developed back-arc or marginal basin where a stable continental shelf may have formed. The lack of sediment contribution from an island arc and the presence of quartzites and arkoses requiring a quartz and potassium feldspar-rich sialic source suggests that if deposition occurred in one of these basins it occurred on the continental side of the basin.

I interpret the Cherry Creek Group as representing deposition in a tectonically stable passive shelf environment, possibly during rifting as indicated by the abundant interlayered amphibolite. The presence of quartzite, conglomerate, and felsic sands indicate a nearby exposed continental source, possibly a granitic terrain. Whether these sediments accumulated along a rifted "Atlantic" style passive margin or the continental side of a back-arc or marginal basin is debatable.

After deposition of the Cherry Creek Group, tectonically stable conditions must have given way to an active tectonic environment. In this environment the pre-Cherry Creek Group and Cherry Creek Group supracrustal rocks were deeply buried where they were subjected to high-grade metamorphism and intrusion by the Dillon gneiss. Pods of meta-ultramafic rock were also introduced just prior to or during this event.

Fountain and Desmarais (1980) suggested that a major crustal suture may exist in the Montana basement. They found similarities with the Wabowden Terrane of Manitoba, in which the Nelson Front is believed

to be a continental suture. They suggest a probable location in the Gravelly and Madison ranges because of an apparent 1.7 b.y to 2.7 b.y. old province boundary in this area. This apparent province boundary has been shown not to exist by recent age dates (James and Hedge, 1980) that have given 2.7 b.y old dates for the rocks earlier believed to be 1.7 b.y. old. The 1.7 b.y. dates (Giletti, 1966) are now thought to represent a minor heating event, possibly related to the Hudsonian Orogeny (Condie, 1976). It is possible that a suture exists in the Montana basement, however, it is unknown at this time. Further correlations of rock packages throughout the Montana basement and an understanding of the relationship between these rock packages may help define these boundaries if they exist.

Continental collision has been suggested as the causes of high grade granulite facies metamorphism in the Adirondacks (McLelland and Isachsen, 1980) and southwestern Norway (Falkum and Petersen, 1980), and provides a mechanism in which the characteristic of the basement rocks of the Ruby Range can be explained. Advantages of a collision environment include;

- 1) It explains the presence of the deeply buried and highly metamorphosed stable shelf sedimentary sequence of the Cherry Creek Group as being caught up between the approaching masses.

- 2) It allows for the presence of meta-ultramafic rocks as tectonically emplaced portions of upper mantle or lower ocean crust, caught up between the colliding masses.

- 3) Collision zones commonly cause crustal thickening. The high

potassium content of the Dillon gneiss, which suggests a crustal source, supports the idea of a thick crust at this time.

4) It provides a reasonable mechanism for burial and heating enough to cause migmatization of the pre-Cherry Creek Group and melting to form the Dillon gneiss.

The proposed tectonic model for the origin of the rocks in the Ruby Range is schematically shown in figure 21, and includes:

1) Deposition of the pre-Cherry Creek Group as a basinal greywacke sequence. A basement-cover or fault relationship between the Cherry Creek and pre-Cherry Creek groups is indicated by the concordant injection of the Dillon gneiss between the two.

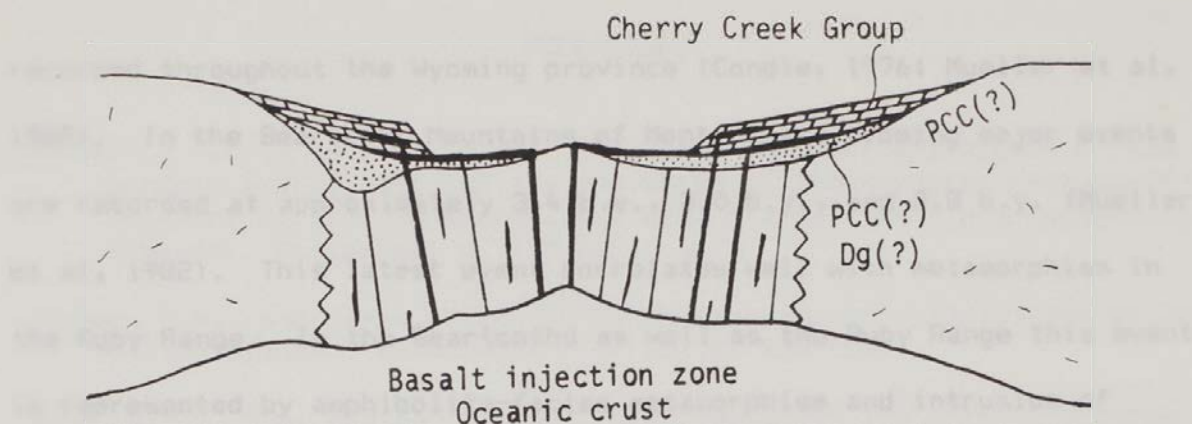
2) Deposition of the Cherry Creek Group in a stable shelf environment, possibly during a period of rifting as indicated by the abundant interlayered amphibolite in this sequence.

3) Upper amphibolite-facies metamorphism, migmatization of the pre-Cherry Creek Group, and intrusion of the Dillon gneiss in a collision environment.

The strict attempt to apply this collision model to the origin of the Ruby Range would be premature with the available data; however, it is worth consideration as model to be tested in the future. Work in correlating events and rock units from different ranges in the Wyoming province and the recognition of possible suture zones are the keys to future interpretations on the origin of any portion of the Wyoming Province in southwestern Montana.

A major orogenic event approximately 2.7 to 2.8 b.y old is

(a)



(b)

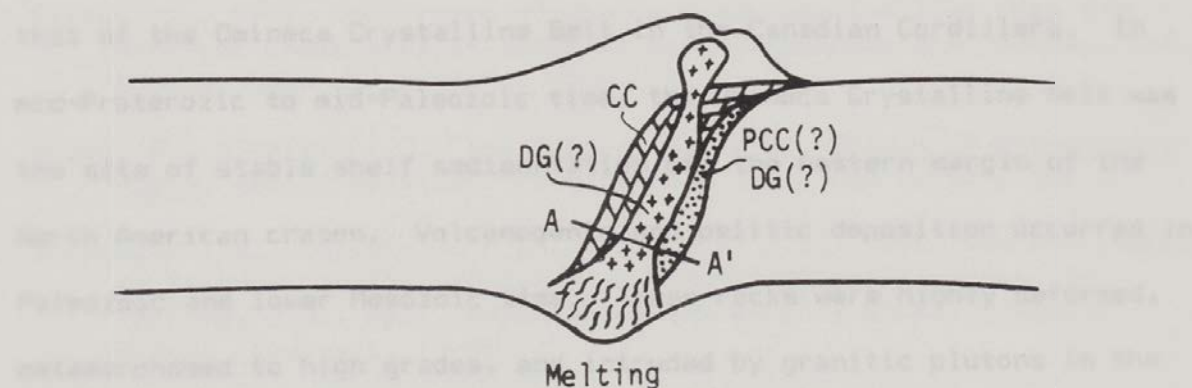


Figure 21. Schematic tectonic diagram showing the proposed model of origin for the Archean rocks of the Ruby Range; CC = Cherry Creek Group, DG = Dillon gneiss, PCC = pre-Cherry Creek Group. (a) Rifting and passive margin deposition of the Cherry Creek Group on the earlier deposited pre-Cherry Creek Group and possibly the Dillon gneiss (if sedimentary in origin). (b) Collision causing burial, metamorphism, deformation, migmatization, and injection of the Dillon gneiss (if igneous in origin). A - A' represents the level exposed in the Ruby Range.

recorded throughout the Wyoming province (Condie, 1976; Mueller et al, 1982). In the Beartooth Mountains of Montana and Wyoming major events are recorded at approximately 3.4 b.y., 3.0 b.y., and 2.8 b.y. (Mueller et al, 1982). This latest event correlates well with metamorphism in the Ruby Range. In the Beartooths as well as the Ruby Range this event is represented by amphibolite-facies metamorphism and intrusion of large quantities of granite and granodiorite. Thus, it is possible that the Ruby Range and Beartooth Mountains were affected by the same process at this time.

An analog to the proposed model of origin for the Ruby Range is that of the Omineca Crystalline Belt in the Canadian Cordillera. In mid-Proterozoic to mid-Paleozoic time, the Omineca Crystalline Belt was the site of stable shelf sedimentation off the western margin of the North American craton. Volcanogenic and pelitic deposition occurred in Paleozoic and lower Mesozoic time. These rocks were highly deformed, metamorphosed to high grades, and intruded by granitic plutons in the mid-Mesozoic to early Tertiary (Monger and Price, 1979; Monger et al, 1982). Early ideas on the origin of this latest event appealed to the Omineca Crystalline Belt as a magmatic arc produced by subduction of oceanic crust. However, the observation that the Omineca Crystalline Belt straddles a collision boundary led to the reevaluation of this idea. The Omineca Crystalline Belt is now viewed partly as the result of tectonic overlap and/or compressional thickening of the crustal rocks during collision between the North American craton to the east and a large allochthonous terrain to the west (Monger et al, 1982).

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